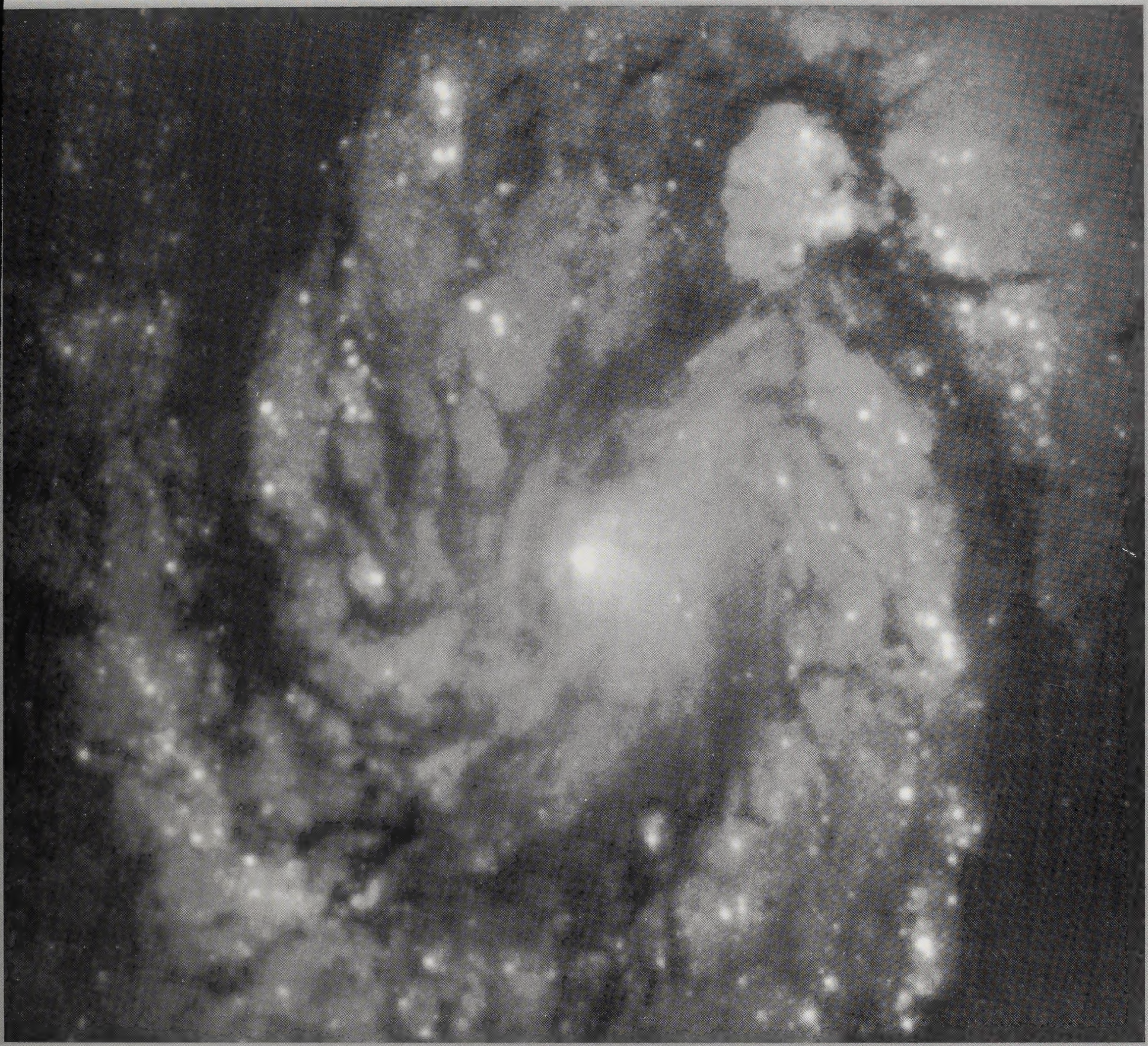
Science 30



MODULE 7

Electromagnetic Energy from the Stars

Distance Learning

Alberta
EDUCATION

Science 30

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Electromagnetic Energy from the Stars

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Module 7
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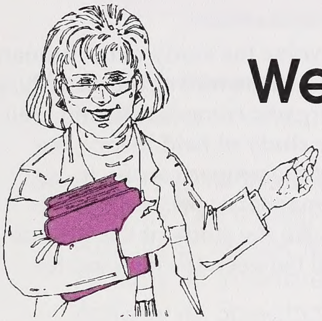


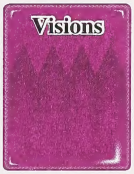
Welcome to Module 7!

We hope you'll enjoy your study of Electromagnetic Energy from the Stars.

To make your learning a bit easier, watch the referenced videocassettes whenever you see this icon.

You also have the option of viewing laser videodisc clips when you see this one.

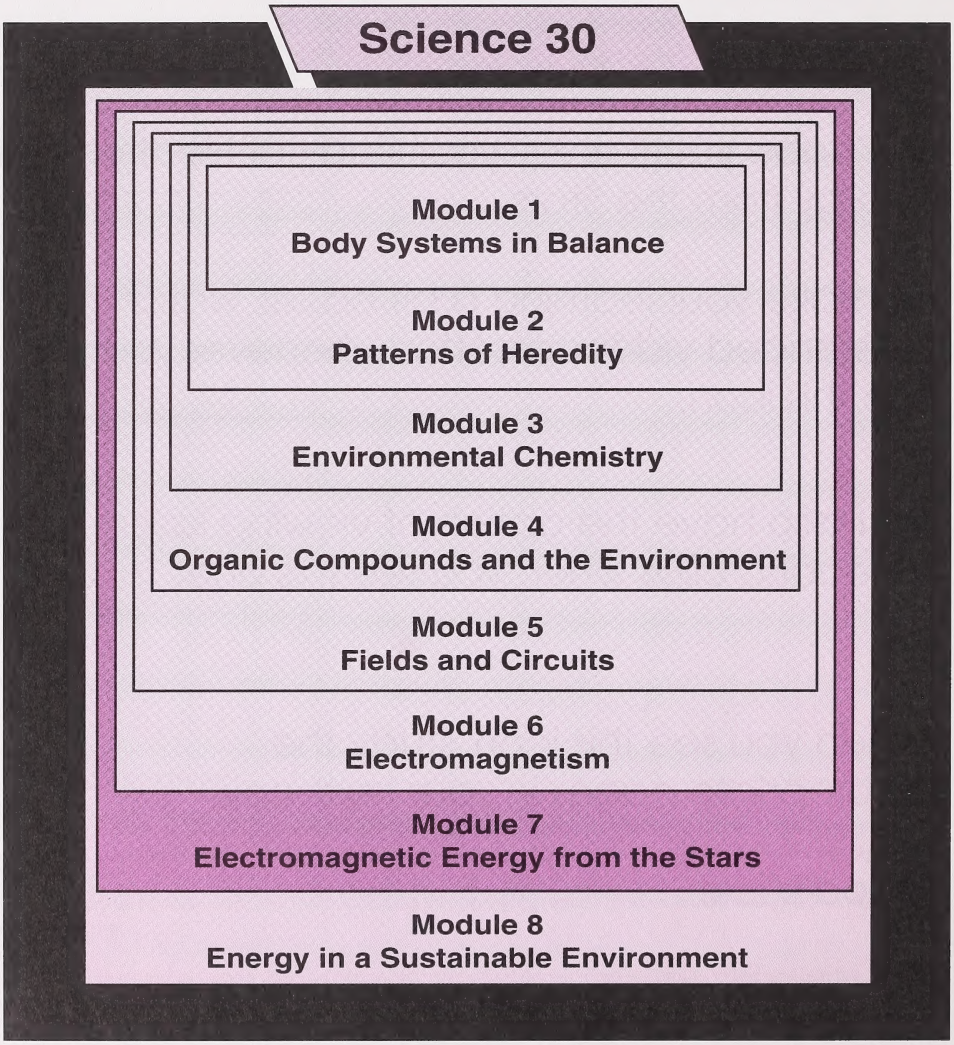
When you see this icon, study the appropriate pages in your textbook.



Good Luck!

Course Overview

This course contains eight modules. Modules 1 and 2 involve the study of the human circulatory system, defence mechanisms, the nervous system, as well as the principles of genetics. Modules 3 and 4 investigate acids and bases, organic compounds, and their effects on the environment. Modules 5 and 6 involve the study of field theory, the operation of various electrical devices, as well as some of the properties of electromagnetic waves. Module 7 focuses on the electromagnetic spectrum and its relation to the study of the Universe. Module 8 will involve the study of the various sources of energy and how a balance must be maintained between the demand for energy and the need to maintain a viable environment.



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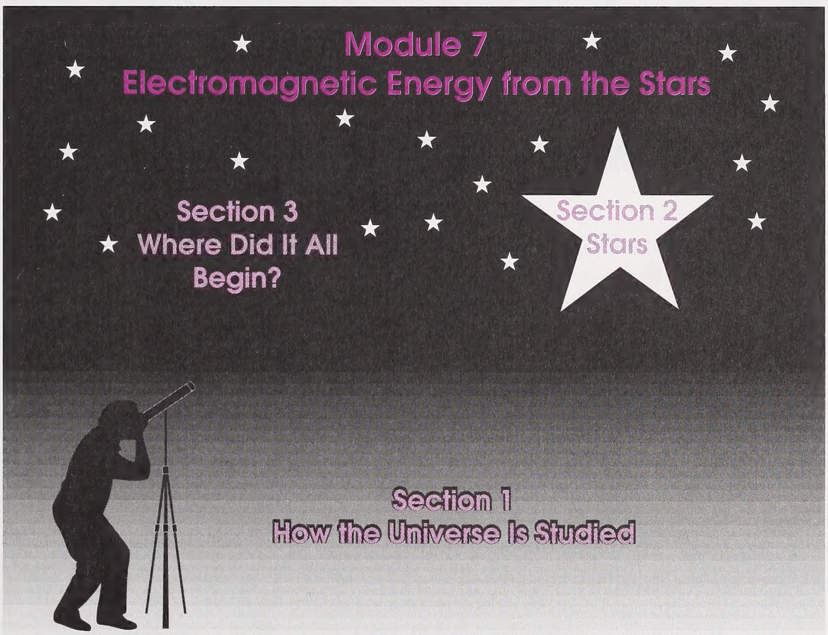
MODULE OVERVIEW

The wonders of the night-time sky have intrigued humans since the beginning of civilization. Phenomena such as the twinkling of a star, the flight of a comet, the sudden plunge of a falling star, the unexpectedness of an eclipse, or the periodic motion of the sun and the moon have mystified people so much, that it is no wonder early civilizations worshipped them. It is also understandable why early science began with a study of the skies.

What are these "lights" in the sky? Where and how did it all begin? Where does Earth fit in? These and other questions have been pondered through the ages. The advances of technology have revealed much, but with each new discovery, comes new questions. Even though many of the old questions have been answered, many more new questions have arisen. What are black holes, quasars, and pulsars? Today, even more than in the past, studies of the heavens entice scientists, and it appears that they are just beginning to reveal many secrets of the universe.

In this module you will be introduced to how information of the universe is gathered and studied. Then you will analyse how stars are classified and how they evolve. Finally, you will analyse theories that try to explain where and how the universe began.



Evaluation

Your mark in this module will be determined by how well you complete the assignments at the end of each section. You must complete all assignments. In this module, you are expected to complete three section assignments. The mark distribution is as follows:

Section 1 Assignment	**30 marks**
Section 2 Assignment	**45 marks**
Section 3 Assignment	**25 marks**
TOTAL	**100 marks**

Section

1 How the Universe Is Studied

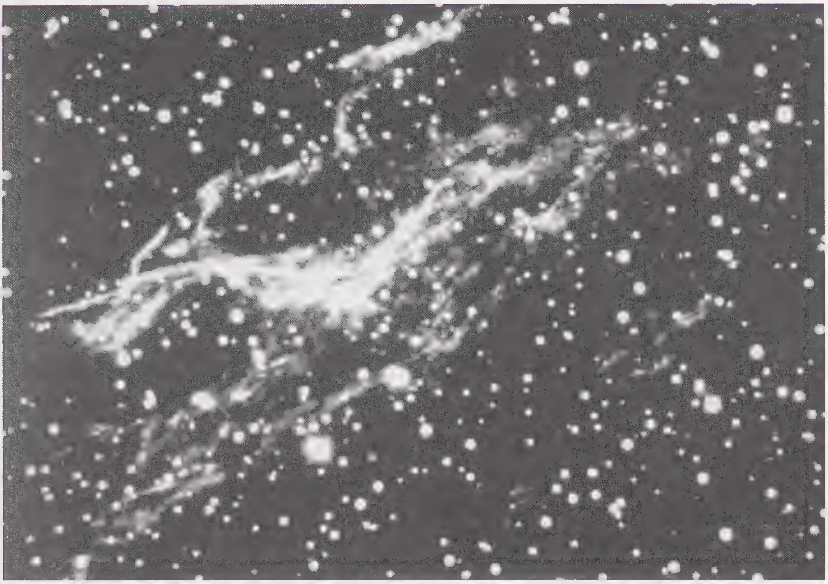


PHOTO SEARCH LTD.

What feelings do you experience when you gaze upward into the night sky? Are you dazzled by the beauty? Are you awed by the vastness of space as it stretches seemingly into infinity? Are you amazed as you visualize the mythical figures formed by the stars? Or, are you simply hypnotized by the wonder of it all?

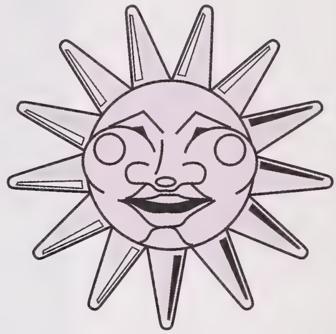
Can you imagine the wonder and the fear early people experienced when they looked upward and tried to comprehend the universe? How did they explain the night sky?

In this section you will initially examine a historical overview of how the first observations of visible light from the universe were interpreted and you will analyse how these initial observations led to an early theory of the universe. Then you will establish how scientists with improvements in technologies distinguished the various properties of visible light (such as propagation of light, reflection, refraction, dispersion, interference, diffraction, and colour), as well as how scientists distinguished visible light as only part of the radiation reaching Earth from stellar objects. Finally, you will generalize how a complete study of the properties of all radiation changed theories into the basic knowledge of the universe that exists today.

Activity 1: Propagation of Light

The earliest studies of the universe began with the science of naked-eye astronomy. It is truly amazing how early scientists were able to interpret patterns in the sky by just gazing with the naked eye for countless hours into the night sky. It is known that early civilizations were able to record the regular passage of lunar changes. It is also important to note, however, that up until modern times, a study of the skies was more a religion than a science. In fact, many cultures today still worship the night-sky phenomena as gods.

Many primitive societies explained all phenomena as the actions of gods. The daily appearance of the life-giving sun was so revered that most primitive cultures worshipped the sun as a god, as evidenced by the names *Sol*, *Tem*, *Baal*, *Helios*, and so on.



For one ancient civilization, the name for one of their gods was *Teotl*. The symbol for Teotl was very similar to the drawing shown to the right.

The regular path of the sun was so carefully studied that the concept of a solar year was eventually developed. Gradually, other regular patterns in the sky were discovered. The various phase changes of the moon were noted and the idea of a lunar month came into existence. Eventually, various patterns of stars were identified as constellations, and the disturbing wanderings of some stars from the regular motion of all stars prompted the discovery of planets. By 600 B.C. enough information about the universe had been gathered to prompt the early Greeks to suggest the first scientific theory of the universe.

To analyse this first theory, read the following paragraph about early Greek astronomers and answer the questions that follow.

More than twenty-five hundred years ago ancient Greeks pictured stars as fixed on the inside of a large rotating sphere. This permanence of the constellations led many early people to name them. From about 600 B.C., Greeks such as Pythagoras, Aristotle, and Plato believed the stars moved in perfect circles around Earth. This belief was maintained until about 200 B.C. when Aristarchus, a Greek astronomer, stated that certain movements of the sky could only be explained if Earth moved around the sun. However, no one believed him. About three hundred years later, another Greek astronomer working in Egypt, also ignored Aristarchus because when he formed his theory of the universe by pulling together the beliefs of those before him, it was Earth-centred! This astronomer's name was Ptolemy and his book became highly respected among Greek and Arab scholars who passed their knowledge on to the Europeans. This work, though wrong, went unquestioned for more than a thousand years.

1. How did the early Greeks picture the position of the stars in the sky?
2. How did the stars appear to move across the night sky according to early Greeks?
3. Who were some of these first Greek astronomers?
4. One early Greek astronomer proposed a theory that contradicted the early Greek theory. Who was he and what was his new theory?
5. Eventually, a Greek astronomer working in Egypt proposed another theory of the universe. Who was he and what was his theory?

Check your answers by turning to the Appendix, Section 1: Activity 1.

Other early civilizations also studied astronomy. The Arabs, Chinese, Moors, and Mayans all contributed improved technologies and contributed much knowledge to the study of the universe.

The astrolabe, which could measure the altitude of celestial bodies above the horizon, and the sextant, which could measure angular distance, were some of the new technologies.

geocentric – Earth-centred universe

The idea of a **geocentric** universe was fundamental to early astronomy in almost all cultures, and it wasn't until the fifteenth century A.D. that a new theory about the centre of the universe began to emerge.

Read the following information regarding the progress of astronomy in the Middle Ages and then answer the questions that follow.

Polish astronomer Nicolaus Copernicus (1473–1543) finally hypothesized that the sun is the centre of the solar system. Although he studied mathematics, law, and medicine, Copernicus spent his life as a church administrator. Martin Luther (1483–1546) a contemporary of Copernicus commented that Copernicus wanted to turn the whole art of astronomy upside down. Copernicus's ideas might have been forgotten if not for a young disciple who convinced him to publish his theories in 1543. Copernicus died the same year.

In Italy an arrogant and witty university lecturer named Galileo Galilei (1564–1642) built a crude telescope on the basis of a "magnifying tube" invented in Holland, thus ending the era of naked-eye astronomy. Galileo defended the Copernican theory; his own sketches from using his telescope showed the moon pockmarked with mountains and craters. With his telescope, Galileo also saw four moons around Jupiter, convincing him that Copernicus was correct. The Catholic church at this time was very strong and this representation of an imperfect heaven was considered heresy. In 1633, when Galileo was seventy, the Inquisition forced him to admit his "errors." It was only in 1979 that the Roman Catholic church began the process of clearing Galileo's name.

6. In 1543 a Polish astronomer published a theory of the universe that contradicted the accepted geocentric universe theory. Who was he and what was his new theory?

7. Who initially opposed this new theory and why?

8. Who defended this new theory?

9. What new technology did Galileo use in his defence of the Copernican theory? Describe how this technology was used.

10. Galileo presented this new knowledge to the scientific community while lecturing at the University at Padua. Who opposed Galileo and why?

11. How was Galileo dealt with?

12. When was the process of clearing Galileo's name finally initiated?

Check your answers by turning to the Appendix, Section 1: Activity 1.

propagation – how light travels from one place to another

Early astronomy concentrated on a study of visible light from the stars and the property of light called **propagation**. Up until the early 1600s, it was thought that the speed of light was instantaneous and that light travelled in a straight line. For example, light would reach Earth from the sun or stars instantly. Around 1850 the speed of light was determined experimentally by Michelson to be 3.00×10^8 m/s. To fully comprehend the magnitude of this speed, do the calculations using the following formula

$$\underbrace{v}_{\text{speed}\left(\frac{\text{m}}{\text{s}}\right)} = \frac{\Delta d \leftarrow \text{distance (m)}}{\Delta t \leftarrow \text{time interval (s)}}$$

DID YOU KNOW?

Light travelling at $3.00 \times 10^8\ \frac{\text{m}}{\text{s}}$ can travel about $7\frac{1}{2}$ times around Earth in 1 s!

13. If light travels at 3.00×10^{8} m/s and if the distance between Earth and the sun is 1.50×10^{11} m, how long does it take for light to reach Earth from the sun?

14. If Pluto is 5.75×10^{12} m from Earth, how long does it take light to reach Earth from Pluto?

15. In comparison, the fastest space probe can travel at 1.15×10^{4} m/s. At this speed how long would it take the space probe to reach Pluto from Earth?

16. If the nearest star, Alpha Centauri A, is 4.07×10^{16} m from Earth, how long would it take the space probe to reach the star?

Check your answers by turning to the Appendix, Section 1: Activity 1.

It was not until scientists performed similar calculations that this new difficulty relating speed, time, and distances between stellar objects was realized. Their calculations revealed for the first time the magnitude of space. As a result, three adjustments were made in the study of space.

First, because distances in space are of such great magnitude, instead of measuring distance in meters, distance is measured in light-years.

To help you in this new measurement of distance, perform the following calculations.

17. Calculate the number of seconds in 1 a of 365 d.

18. If light can travel at 3.00×10^{8} m/s, how far can light travel in 1 a?

Check your answers by turning to the Appendix, Section 1: Activity 1.

From these calculations, it can be concluded that

> 1 light-year = the distance light can travel in 1 a or 9.46×10^{15} m
>
> Remember: 1 light-year is a measurement of distance not time.

19. The nearest star, Alpha Centauri A, is 4.07×10^{16} m from Earth.

    a. How many light-years is it away from Earth?

    b. What is the advantage of stating stellar distance in light-years rather than meters?

Check your answers by turning to the Appendix, Section 1: Activity 1.

The second adjustment in the study of space concerned the dream of interstellar travel. Ideally, the most advantageous method of studying the universe would be to actually travel to the distant stars. However, because your calculations determined that a space probe would take 1.12×10^{5} a to travel to the nearest star, the dream of interstellar travel was shattered.

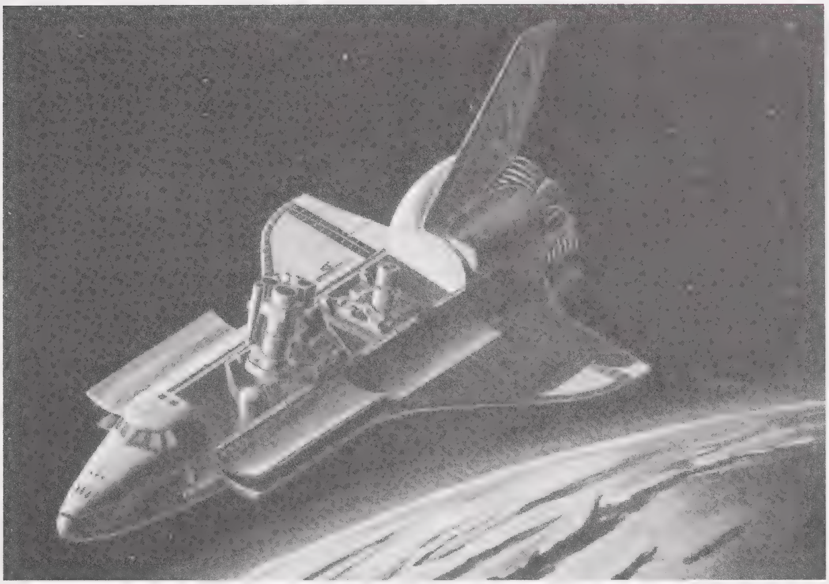
The third adjustment revealed an exciting hypothesis. If light from Alpha Centauri A takes 4.30 a to reach Earth, then the light seen at this moment, took place on Alpha Centauri A 4.30 a ago. Because a study of this light is not an accurate picture of that star, this is a disadvantage. The advantage is that a study of light from the stars can reveal what has occurred in the past. Studies of light from deep space might reveal information that occurred billions of years ago and, quite possibly, light from the outer edges of the universe could reveal the creation of the universe itself.

In this activity you have studied a brief overview of the history of astronomy and you have discovered how a study of one property of visible light—propagation—was used to gather information about the universe. In the next activity you will analyse how a study of other properties of light and improved technologies aided the process of interpreting the universe.

Activity 2: Reflection and Refraction of Light

Early science derived all the initial information about the universe from a study of the visible light propagating from stellar objects and from the science of naked-eye astronomy. As time progressed, however, the quest for more accurate knowledge prompted the development of new technologies.

What were some of these new technologies? How did these technological inventions aid scientists in gathering information, and what type of new information were they able to obtain?



NASA

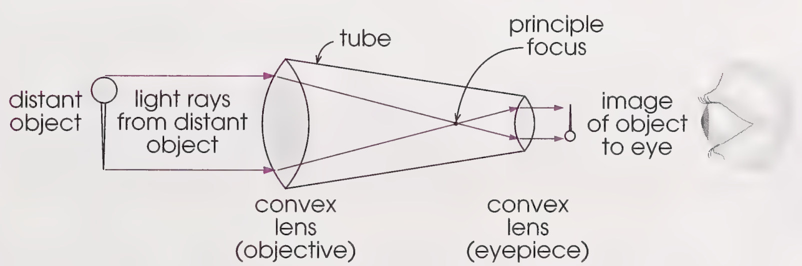
This activity will follow the advancement of some new technologies and the efforts to discover the secrets of the universe.

The end of the era of naked-eye astronomy and the birth of modern astronomy began in the 1500s with the development of the first crude telescope by Galileo.

To study the development of this new technology, read pages 336 to 338 in *Visions 3*, and answer the questions that follow.

The following diagram depicts the operation of a simple astronomical telescope.

Model of an Early Telescope

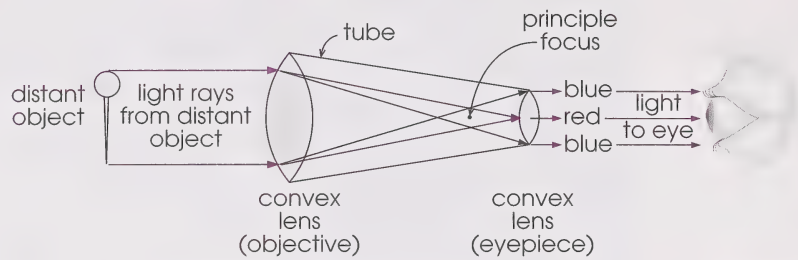


In the previous module you studied two additional properties of light—reflection and refraction of light.

1. Which property of light is used in the operation of this telescope?

2. The following diagram depicts a fault that was associated with this type of telescope.

Model of an Early Telescope



   a. What is the name of this fault?

   b. What is the cause of this fault?

   c. According to your textbook, how can this fault be corrected?

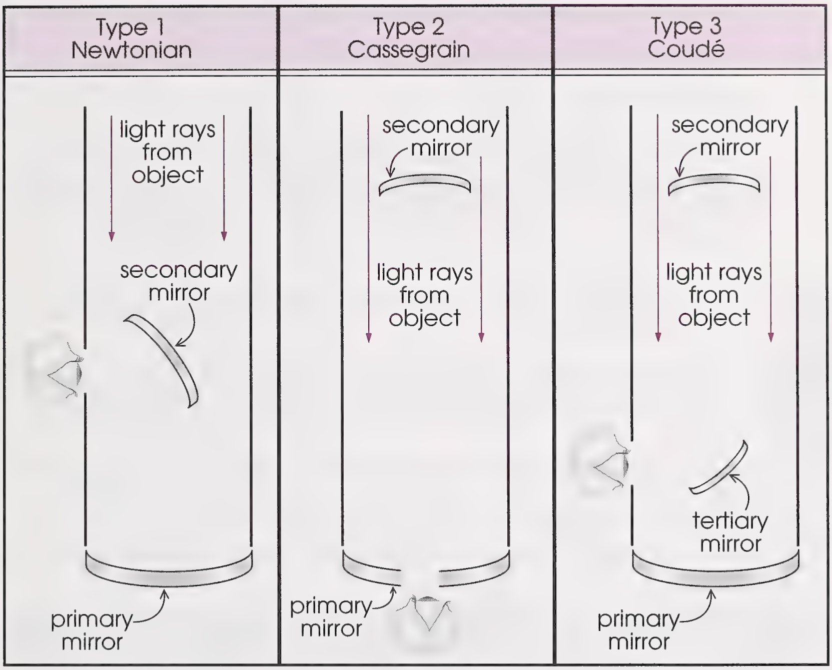
   d. How big is the largest refractor telescope ever made?

Check your answers by turning to the Appendix, Section 1: Activity 2.

Isaac Newton began his study of the properties of light in 1672. His first invention was another type of telescope that overcame the difficulties of Galileo's refracting telescope.

3. Upon what property of light does Newton's telescope operate?

4. The reflecting telescope has three common arrangements of interior mirrors and eyepieces as shown in Figure 10.9 on page 337 of your textbook. Copy each of the following diagrams and draw the path of light rays from the object to the eye.



5. As technology advanced new devices for the reflecting telescope were developed to enhance the optical imaging. One of these devices is a charge-coupled device. Explain it operation.

As the telescope improved new knowledge about the universe was rapidly being obtained—even by amateur astronomers. However, the beginnings of modern astronomy were still ground based or on the surface of Earth. Even though astronomers tried to situate their telescopes in the most advantageous positions, it was often very difficult to obtain a clear image of a stellar object.

6. Why was it difficult to obtain a clear image for the early ground-based astronomers?

7. How did scientists try to overcome this problem?

Check your answers by turning to the Appendix, Section 1: Activity 2.

Another major advancement in astronomy began around 1850 with a remarkable hypothesis by a clever mathematician named Maxwell. Historically, the visible light from the sun and stars was the only source of information about the universe. But an analysis of the visible light from a celestial body can only reveal the position, brightness, or possibly the topography of that stellar object.

The hypothesis by Maxwell revealed that visible light is merely a small component of the entire range of radiation, known as the Electromagnetic Radiation Spectrum, that emanates from objects. This spectrum is shown at the start of the colour pages at the end of the Appendix.

As technology improved scientists were able to detect and analyse these other invisible components of the Electromagnetic Radiation Spectrum radiating through space from the stars. An analysis of these radiations revealed much new information about the universe.

Visions

To learn about this new information, read pages 334 to 339 of your textbook and answer the following questions.

8. Which radiations from space can penetrate Earth's atmosphere completely and reach the surface of Earth? Which radiations partially reach the surface of Earth?

9. What three important discoveries in space were made by a study of radio waves?

See Plate 10.3 on P–24 of the colour pages of *Visions 3* for a radio image of the region surrounding the star called Sagittarius A near the centre of our galaxy.

10. Infrared radiation also reveals unique information.

    a. What types of stars emit infrared radiation?
    b. What does infrared radiation reveal best?
    c. What can infrared radiation pinpoint?

Visions

See Plate 10.5 on P–24 of *Visions 3* for an infrared image. The image shows the dust in the region of a newborn star. Infrared radiation does not reveal the star but the dust that is heated by the star.

11. All other radiations are blocked, to some extent, from reaching Earth's surface. Complete the following table to analyse how and where blockage of radiation occurs.

Type of Radiation	Position in atmosphere where blockage occurs	Substance involved in blocking radiation
Ultraviolet		
X-ray		
Gamma		

Check your answers by turning to the Appendix, Section 1: Activity 2.

12. The study of x-rays and gamma rays revealed interesting astronomical data.

    a. Where do these rays originate from in space?

    b. What specific information can x-rays reveal?

    c. Why can black holes not be viewed directly?

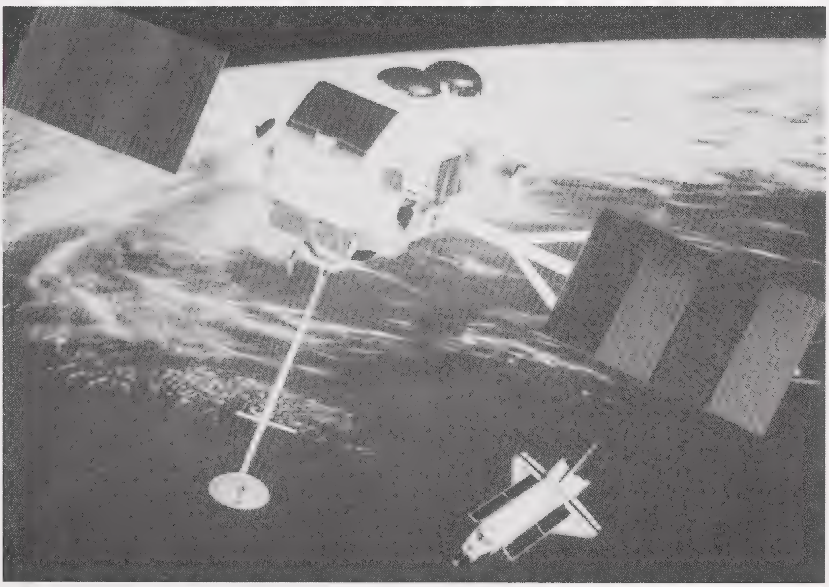
    d. How can x-rays reveal black holes?

    e. What can the study of gamma rays reveal?

Visions

See Plate 10.6 on P–25 of *Visions 3* for an x-ray image of extremely hot gas in the Milky Way Galaxy. Note how the x-ray image reveals the violent motion of the gases.

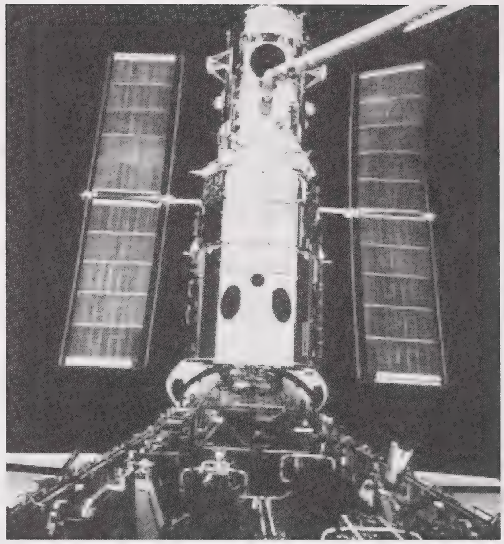
The following photograph shows the Gamma Ray Observatory which was launched aboard the Space Shuttle Atlantis on April 5, 1991. Its purpose is to investigate gamma radiation, the most energetic form of radiation known, and its sources—pulsars, quasars, and possibly black holes.



NASA

Although scientists tried to perfect their methods of detecting all radiation using ground-based telescopes, they realized that space-based astronomy would be more advantageous.

The photograph on the right shows the Hubble Space Telescope in repair in December 1993. The telescope, when first launched in 1990, produced fuzzy images due to imperfections in the mirror. The repair mission added a corrective lens. See the end of the Appendix for colour before-and-after images taken by the Hubble Space Telescope.



NASA

Visions

Reread page 338 of *Visions 3* for information on space-based observatories and answer the following questions.

13. Explain why space-based astronomy is more advantageous than ground-based astronomy.

14. List some examples of attempts at situating observatories in space.

The colour pages at the end of the Appendix show some images taken with UV light. These include the M74 Spiral Galaxy with UV light and Omega Centauri with visible light and UV light. Notice how the visible light (red image of Omega Centauri) highlights the dense star population while the ultraviolet image shows only the hotter high-energy stars. In the M74 Spiral Galaxy it is the hot central core of the galaxy that is predominant in the UV light image. Thus each different electromagnetic wave provides different information from stellar images.

The rapid advancement of technology in the twentieth century and the scientist's curiosity for a closer look sparked the final stage in astronomy. The age of actual space travel began and the study of astronomy was enhanced by manned flights to the moon and several space probes to various parts of the universe.

15. Name two well-known probes and describe what they revealed.

16. a. What is an advantage of space travel?

    b. What is a disadvantage of space travel?

Check your answers by turning to the Appendix, Section 1: Activity 2.

You may wish to watch the video titled *NASA Space: New Universe*, ACCESS Network, for more information on neutron stars, black holes, and quasars. You may be able to obtain this video through your school or local library.

This activity analysed how technology can use the properties of reflection and refraction of visible light to study the universe and how other forms of radiation that emanate from the stars can be used to reveal important information about the universe. It also outlined three methods of astronomy (ground-based, space-based, and space probes) and discussed how the advancements in technology favoured the development of each. The advantages and disadvantages of each method were also analysed. In the next activity you will study how other properties of light can reveal added information about stellar objects.

Activity 3: Interference and Diffraction of Light

In the previous activity you analysed how two properties of light—reflection and refraction—enabled scientists to study the universe. These properties, however, can only provide information concerning the position, brightness, and topography of stellar objects. You also learned that different radiations comprise the entire electromagnetic spectrum emanating from stellar objects. But are these radiations particles or waves? Where do the different colours of light originate?

In this activity you will study how an analysis of two other properties of light—interference and diffraction—can be used to determine the nature of light and explain the origin of colours of light.

Historically, as scientists studied the properties of light, two opposing theories of the nature of light evolved.

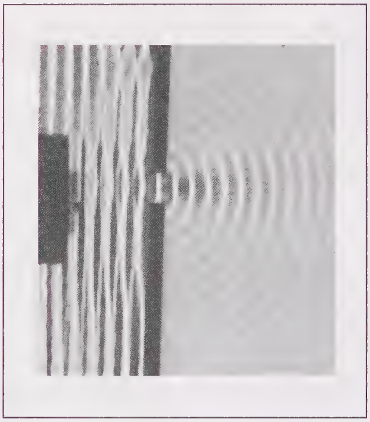
Newton (Particle Theorist)

Huygens (Wave Theorist)

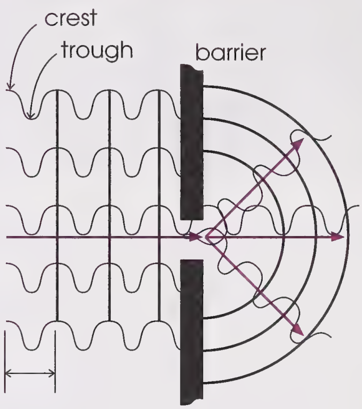
By the 1600s some scientists, led by Newton, supported the ancient Greek theory that light travelled as tiny invisible particles. Others, led by Huygens, believed that light travelled as waves. In the 1600s, analysis of the properties of propagation, reflection, and refraction of light failed to prove either theory.

However, if light is a wave it should display the properties of interference and diffraction similar to water or sound waves.

To analyse the property of diffraction, first study the following diagram and then answer the questions that come after.



Overhead photo of water waves passing through an opening produced by a barrier



Planar Water Waves

Semicircular Water Waves

Diagram displaying how planar water waves passing through an opening in a barrier produced semicircular waves

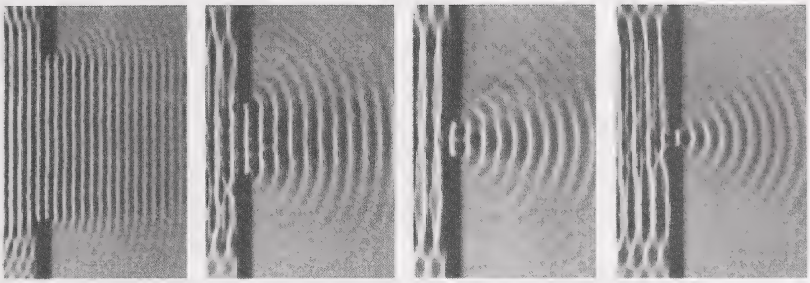
planar water waves – waves that are travelling in one direction or plane

1. a. What happens to **planar water waves** as they pass through an opening or a slit?

   b. What is this property of waves called?

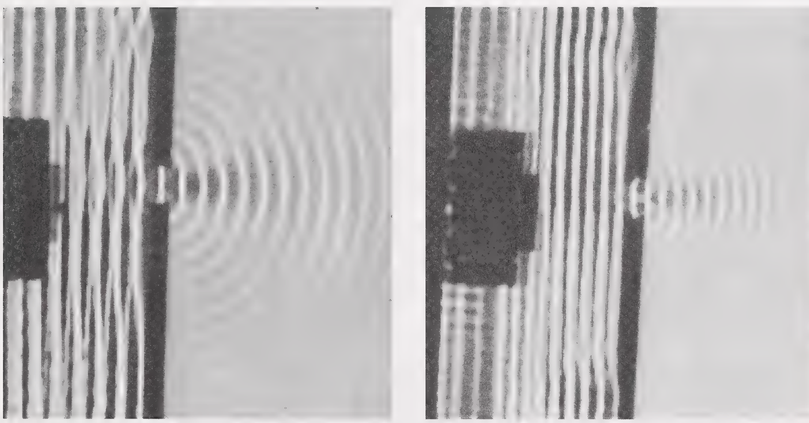
   c. The following photographs display one factor that determines the amount of diffraction.

After studying these photographs, describe this factor that affects the diffraction.



d. The next photographs display another factor that determines the amount of diffraction.

After studying these photographs, describe the second factor that affects the diffraction.



e. In the previous module, you learned that all waves have speed (v), frequency (f), wavelength (λ) and period (T).

i. What is the mathematical relationship between v, f, and λ?

ii. What is the mathematical relationship between f and T?

iii. Based on your observations of the photographs, does diffraction affect the velocity (v), frequency (f), wavelength (λ), or period (T) of a wave?

f. Do you think that a particle like a bullet travelling through an opening, such as a doorway will exhibit diffraction?

g. What conclusion can be stated concerning diffraction and the particle or wave theories?

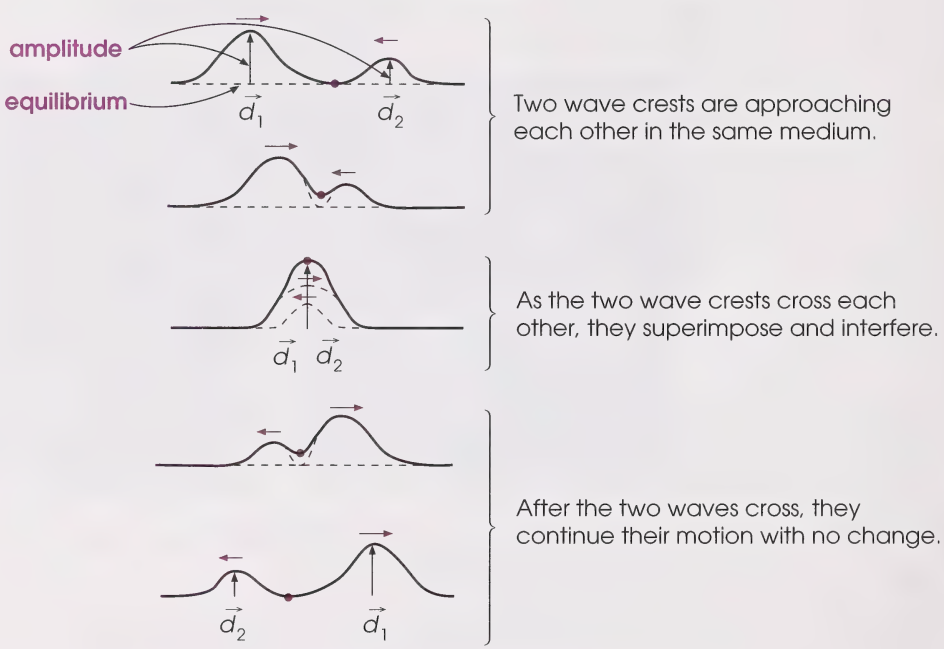
Check your answers by turning to the Appendix, Section 1: Activity 3.

To analyse the property of interference, study the following diagram and answer the following questions.

amplitude – the maximum displacement of the wave from the equilibrium position

equilibrium – the rest position of the wave where no net forces act on the wave

Two Wave Crests Interfering Constructively



constructive interference – the result of two waves adding together

The type of interference shown in the preceding diagrams is called **constructive interference**. When two crests or troughs approach each other in a way in which their amplitudes will combine completely as shown in the preceding diagram, the waves are said to be in phase. The result of two waves interfering constructively is called an antinode.

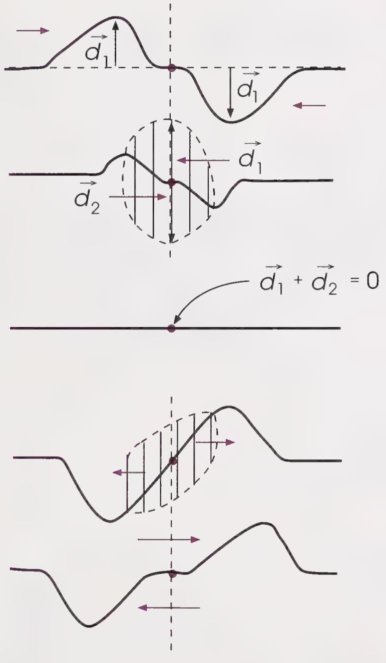
2. If one wave crest has an amplitude of 2.00 cm and the other crest has an amplitude of 1.00 cm, what will be the amplitude of the resulting wave when they interfere constructively? This is called the **law of superposition**.

law of superposition – the amplitude of the resulting wave is determined by adding the displacements of the individual waves superimposing

Check your answers by turning to the Appendix, Section 1: Activity 3.

Study the following diagrams.

A Wave Crest and a Wave Trough Interfering Destructively



A wave crest and a wave trough are approaching each other in the same medium.

As they cross each other they superimpose and interfere.

After the two waves cross each other, they continue their motion with no change.

destructive interference – the result of a crest and a trough cancelling each other partially or completely

The type of interference shown in the preceding diagram is called **destructive interference**. When a crest and a trough approach each other in a way that their amplitudes negate each other, they are said to be out of phase. The result of two waves destructively interfering is called a node. A crest and a trough will reduce each other to zero amplitude only if their amplitudes are the same. Otherwise the resulting amplitude is the difference of the two amplitudes.

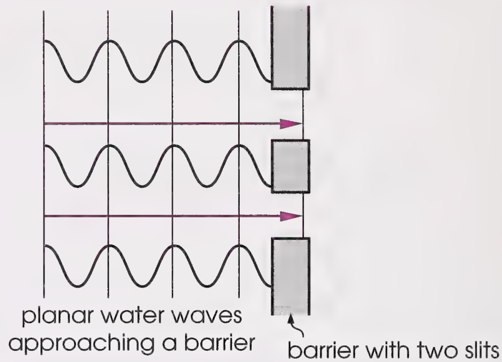
3. a. If two waves had amplitudes of 2.00 cm and -1.00 cm respectively, what is the amplitude of the resulting wave when they superimpose?

   b. Do you think that two particles like two bullets can interfere constructively or destructively?

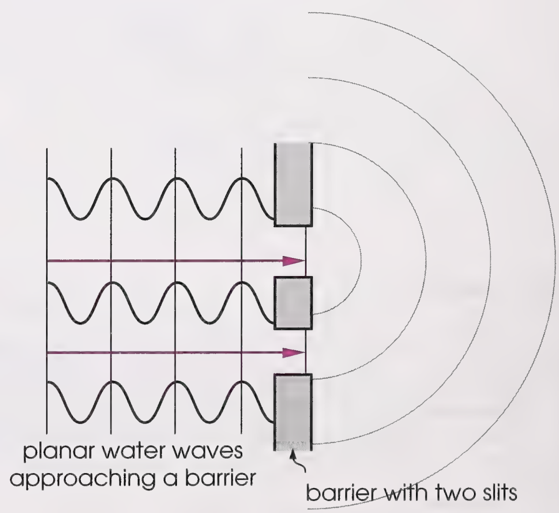
   c. What conclusion can be stated concerning interference and the particle or wave theories?

Check your answers by turning to the Appendix, Section 1: Activity 3.

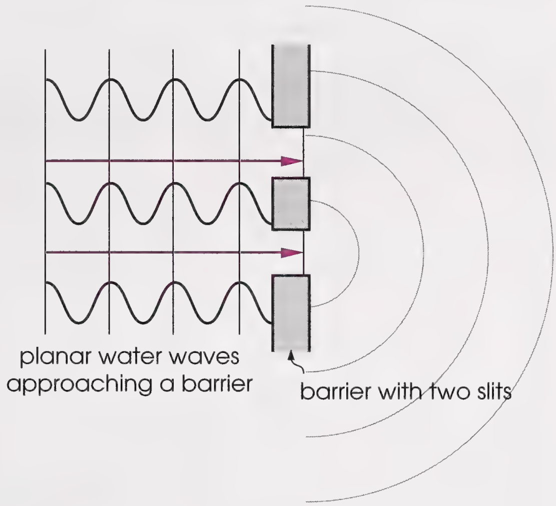
Suppose that the properties of diffraction and interference were now involved in the same situation. To study this more closely, suppose planar water waves were approaching a barrier with two slits, as shown in the diagram on the right.



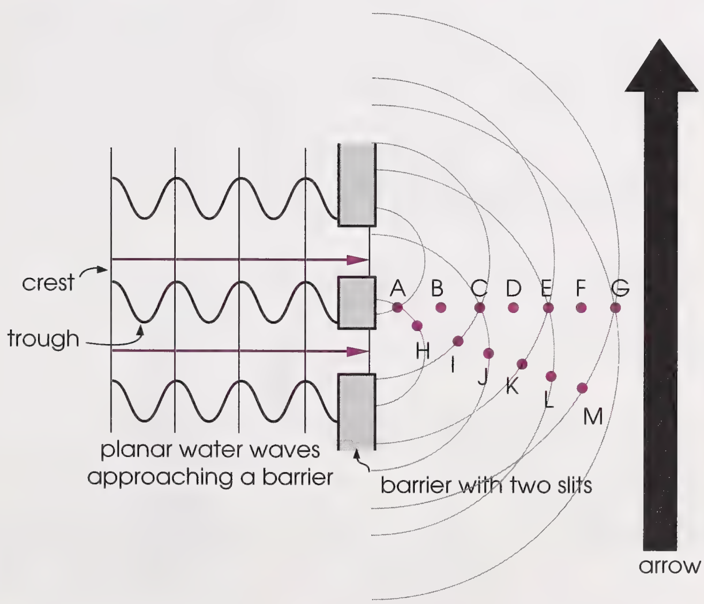
As the waves pass through the top slit they will diffract as shown in the diagram on the right.



At the same time, as waves pass through the bottom slit, they will also diffract as shown in the following diagram.



Since both diffractions are occurring simultaneously, they will superimpose as shown in the following diagram.



4. Use the preceding diagram to answer the following questions. Note that each arc in the diagram represents a crest and the space between each arc represents a trough.

   a. Complete the following table.

Point	What type of waves are superimposing at each point?	What type of interference is occurring at each point?	What is the name of the resulting wave at each point?
A			
B			
C			
D			
H			
I			
J			
K			

   b. Draw a line through points A to G. What name could be given to this line?

   c. Draw a line through points H to M. What name could be given to this line?

   d. Draw two other antinodal lines on the diagrams and draw one other nodal line on the diagram.

   e. If you walked along a line depicted by the large arrow on the right, what would you experience as the resulting water waves struck you?

This pattern of nodal and antinodal lines is called an interference or diffraction pattern.

   f. What is the cause of this pattern?

   g. Could particles passing through these same slits produce a similar pattern?

   h. What conclusion can be made concerning diffraction and interference and the particle or wave theories?

Check your answers by turning to the Appendix, Section 1: Activity 3.

If it can be shown that light behaves like all other waves and that light will diffract and interfere producing a diffraction pattern, then it can be proven that Huygens was right!

Do the following investigation to prove the wave theory of light.

Science Skills
- [ ] A. Initiating
- [x] B. Collecting
- [x] C. Organizing
- [x] D. Analysing
- [x] E. Synthesizing
- [ ] F. Evaluating

Investigation: Diffraction and Interference of Light

Purpose

In this investigation you will attempt to observe and analyse qualitatively the diffraction and interference of light using a **diffraction grating**.

diffraction grating – a transparent film with multiple slits

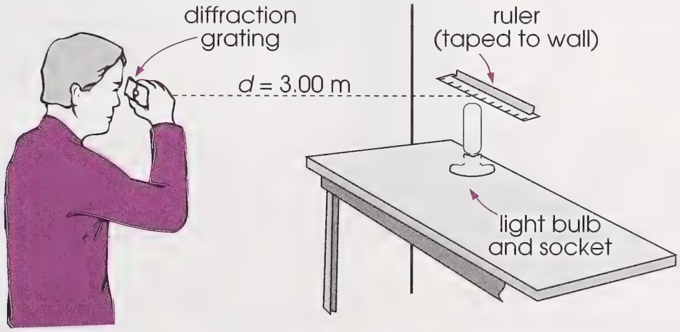
Materials

You will need the following materials for this investigation.

- tape
- showcase light bulb and socket
- ruler (use a metre stick or make a ruler 100 cm long out of cardboard)
- blue and red filters
- diffraction grating (5315 lines/cm or diameter of slit $= 1.88 \times 10^{-6}$ m)

Procedure and Observations

- Using the ruler measure a distance 3.00 m on the floor perpendicular to a wall.
- Mark the spot on the floor with a piece of tape.
- Set up the apparatus as shown in the following diagram.



- Darken the room and plug in the bulb.

- Stand on the marked spot and using the diffraction grating, look directly at the bulb through the diffraction grating. Do not stare directly at the bulb without the diffraction grating as it may cause eye damage.

5. Make a chart like the one that follows question 9. Sketch the patterns you observe (especially noting the colour sequences) in the proper column of the chart you made.

6. What is this pattern called?

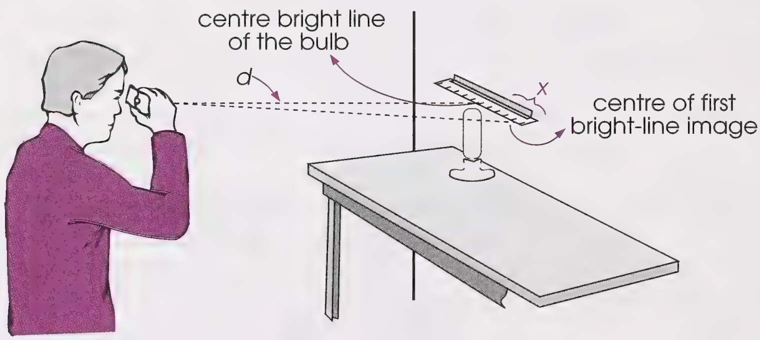
- Unplug the bulb. Let the bulb cool for 1 or 2 min. Tape the red filter around it. Be sure all of the bulb is wrapped with the red filter.

- Plug in the bulb.

- Stand on the marked spot and using the diffraction grating, look directly at the bulb.

7. Sketch the pattern you observe in the proper column of the chart that you made. The bright line image on the sides should only be red now.

- Using the ruler as a reference, measure the distance (x), to the nearest centimetre, from the centre bright line of the bulb to the centre of the first bright line image of the pattern, on one side only. Note: You may wish to have a helper mark the spot that you indicate on the ruler. (Refer to the following sketch.)



8. Record your measurement of the distance in the proper column of the chart that you made. Unplug the bulb and let it cool again for 1 or 2 min.

- Replace the red filter with a blue filter; repeat the procedure.

9. Record your measurement for the x value for blue light in the proper column of the chart that follows.

OBSERVING DIFFRACTION PATTERNS		
Light Source	**Sketch of the observed pattern**	**Distance from centre bright line to centre of 1st bright image line x (cm)**
White Light		
Light with Red Filter		
Light with Blue Filter		

Check your answers by turning to the Appendix, Section 1: Activity 3.

Analysis and Interpretation

10. Based on your observations, does light diffract and interfere producing diffraction patterns?

11. Does this experiment prove the wave theory or the particle theory of light?

12. What additional theory does this experiment display concerning the nature of white light?

13. Which colour of light appears to diffract the most?

14. If different colours diffract different amounts, what does this suggest about the wavelengths of different colours of lights?

15. Which colour of light would seem to have the largest wavelength?

Check your answers by turning to the Appendix, Section 1: Activity 3.

This experiment was actually performed in the early 1800s by Thomas Young. Using a similar procedure, with a double slit instead of a diffraction grating, he was able to demonstrate, not only that light behaves like a wave, but he was able to calculate the actual wavelengths of the different colours of light that comprise white light.

Thus, the light from the stars and other stellar objects must be travelling through space as a wave. In the next activity you will study how the different colours of light could be used to study the composition and chemical makeup of stellar objects.

Activity 4: Spectral Fingerprinting

If you look upward into the night sky you may see countless numbers of stellar objects, all seeming to emit the same white light. However, if these same stars are exposed on colour film some stellar objects appear yellow, others red, and still others any colour imaginable. What information can these different colours reveal about a particular stellar object?

NASA

spectral fingerprinting – using bright-line emission and dark-line absorption spectra to identify the type of element in a sample

The answers to this question will be revealed in this activity as you study the science of **spectral fingerprinting**. This science actually began in the 1700s when it was observed that under certain conditions three different types of spectra can be produced.

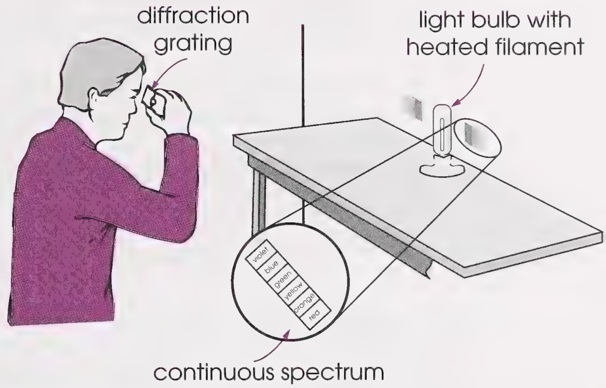
To learn more about how these spectra are studied, analyse the following descriptions and answer the following questions.

continuous spectrum – a spectrum in which all the colours of the visible spectrum are observed, similar to a rainbow

First Type of Spectrum

When the light emitted from a glowing solid is viewed through a diffraction grating, a **continuous spectrum** is observed.

The glowing solid in this example is the wire filament in the bulb which is heated by an electric current.

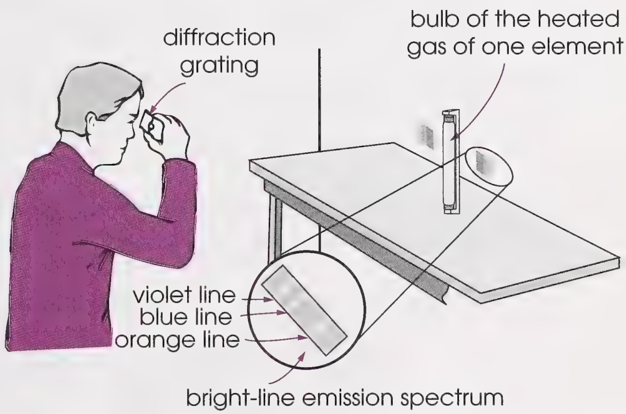


bright-line emission spectrum – a spectrum in which only a few distinct colour lines are observed

Second Type of Spectrum

When the light emitted from a glowing gas is viewed through a diffraction grating, a **bright-line emission spectrum** is observed.

The glowing gas in this example, is heated by an electric discharge apparatus.

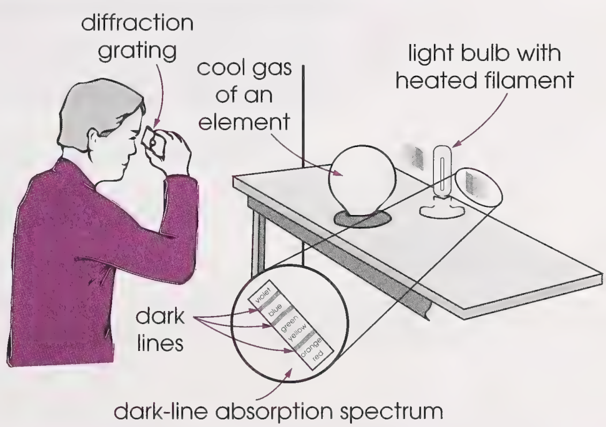


dark-line absorption spectrum – a spectrum in which all the colours are observed with a few distinct dark lines

Third Type of Spectrum

When the light emitted from a glowing solid passes through a cool gas and is then viewed through a diffraction grating, a **dark-line absorption spectrum** is observed.

The glowing solid in the bulb with a filament emits light with a continuous spectrum which then passes through the cool gas of an element.



1. a. Describe a similarity between the spectra observed in the bright-line spectra and the dark-line spectra.

   b. What assumption can you make about the glowing gas in the bright-line spectrum and the cool gas in the dark-line spectrum?

Check your answers by turning to the Appendix, Section 1: Activity 4.

After comparing the bright-line emission and the dark-line absorption spectra of many different elements, scientists realized that not only will an element always emit a unique set of bright lines, different from every other element, but it will also absorb those same lines in the dark-line spectrum. By studying these spectra scientists could identify the type of element in a sample and the science of spectral fingerprinting began.

In the colour pages for Module 7 at the end of the Appendix are the bright-line emission spectra of three known elements. Study these spectra carefully, noting the position of each colour for each element.

Suppose you were analysing the emission spectra of an unknown gas and you observed the spectrum shown for question 2. a. at the end of the Appendix.

2. a. What elements can you assume are in the gas sample?

   b. If this spectrum was the observed spectrum of a distant star, what could you assume about that star?

Check your answers by turning to the Appendix, Section 1: Activity 4.

This method has enabled scientists to determine the elements present in a stellar object without ever having to travel to the object. Also, scientists can determine the nature of elements in the cool gas clouds surrounding a stellar object by studying its absorption spectrum.

Do the following investigation to see how the absorption spectrum of the sun can determine the elements present around the sun.

Investigation: The Solar Absorption Spectrum

Purpose

The purpose is to observe and analyse the absorption spectrum of the sun.

Materials

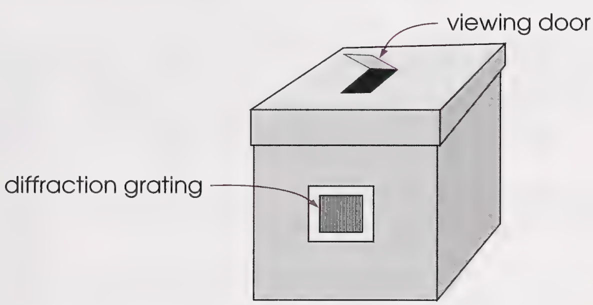
- diffraction grating (diameter of slit $= 1.88 \times 10^{-6}$ m)
- shoe box
- scissors
- masking tape or cellophane tape

Procedure

- Cut a hole, slightly smaller than the diffraction grating, at one end of the shoe box.

- Tape the grating over the hole.

- Cut a trap door in the lid of the box so that when you peek through the trap door, you can view the inside end of the box opposite your diffraction grating. Your apparatus should be similar to the following diagram.



- Aim the box at the sun with the diffraction grating toward the sun.

Do not look directly at the sun as its intense radiation can cause permanent eye damage.

- Look through the trap door and observe the spectrum on the inside back end of the box.

Observations

3. What type of spectrum did you observe?

Analysis and Interpretation

4. Why does the sun generate a full spectrum?

5. Since you observed dark-lines in the full spectrum, what does this suggest about the nature of the atmosphere surrounding the sun?

6. What is the atmosphere surrounding the sun called?

7. Using your results, is the absorption spectrum missing two dominant yellow lines?

8. Which element does this suggest is present in the sun's corona?

Check your answers by turning to the Appendix, Section 1: Activity 4.

By studying the emission spectra, scientists can determine the elements present or the chemical makeup of a stellar object, and by studying the absorption spectrum, scientists can determine the elements in the atmosphere surrounding the stellar object. But the reason why a particular element can emit only certain bright lines and absorb these same lines under different conditions remained a mystery until the 1900s when a Danish scientist, Niels Bohr, related these lines to the structure of the atom.

He proposed that the electrons surrounding the nucleus of a particular atom can exist in definite energy levels and the spectra are produced when this electron jumps from one level to another.

Read pages 330 to 331 of your textbook and answer the following questions.

9. When an electron jumps up to a higher level, does it absorb or emit energy?

10. What does it absorb this energy from?

11. If the electron absorbs this energy from full spectrum light, what type of spectrum will be observed?

12. What type of state will the electron be in this higher orbit or energy level?

BETTMANN ARCHIVES NIELS BOHR

13. When the electron drops back down to its original energy level, does it absorb or emit energy?

14. What type of spectrum will be observed in this case?

15. Why are the emission and absorption lines for a particular element identical?

Check your answers by turning to the Appendix, Section 1: Activity 4.

In this activity you have studied how the science of spectral fingerprinting can reveal the chemical makeup of distant stellar objects and you were also introduced to how this relates to the Bohr Model of the atom.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

In this section you studied how several properties of light reveal information about the universe. These properties are propagation, reflection and refraction, and diffraction and interference. Answer the following questions with regard to these properties.

1. a. How fast does light and all electromagnetic radiation travel?

   b. What information can propagation of light reveal about the universe?

   c. Is the light-year a measure of distance or time?

   d. What is a light-year?

2. a. What type of technology gathers information about the universe by using reflection and refraction of light?

   b. Who developed the first refracting telescope?

   c. Who developed the first reflecting telescope?

   d. Name three types of reflecting telescopes?

   e. Name two electromagnetic radiations that reach telescopes on Earth's surface.

f. What information about the universe can be gathered using telescopes that use reflection or refraction of light?

3. a. What information about electromagnetic radiation does diffraction and interference of light provide?

   b. Name three types of spectra observed by the diffraction and interference of light.

   c. What type of information about the universe can be gathered from spectra?

Check your answers by turning to the Appendix, Section 1: Extra Help.

Enrichment

Do one or more of the following.

On page 350 of your textbook are questions under the Decide and Projects section.

1. Do Textbook question 1 and 2 from the Decide section

2. Do Textbook question 2 from the Projects section.

Check your answers by turning to the Appendix, Section 1: Enrichment.

Conclusion

In this section you analysed how scientists use the various properties of light and other electromagnetic radiation to gather information about stellar objects. You also established how as technologies improved, the amount and quality of information improved.

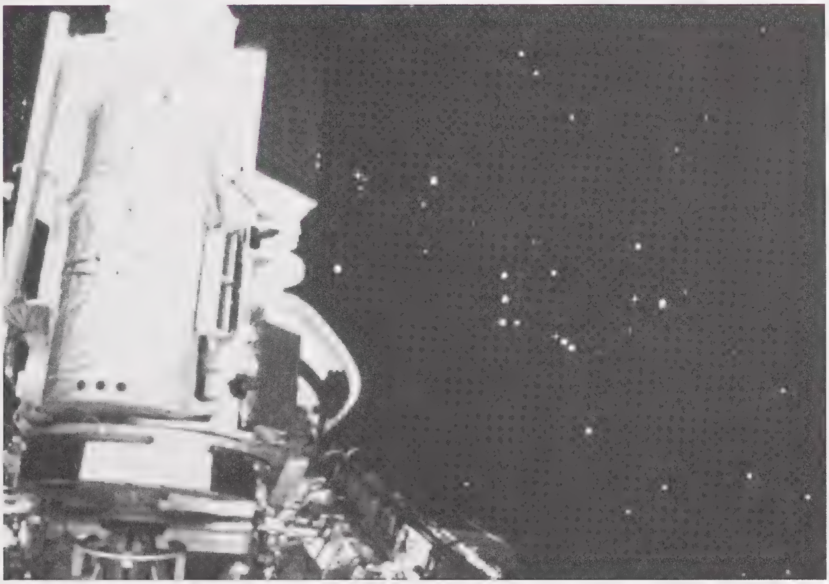
In the next section you will theorize how this information is used to formulate theories about stars.

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 1.

Section

2 Stars



NASA

The black and white photograph of the constellation Orion shown here is how you would see it if you looked up into the sky on a clear night. See the same Orion constellation photograph taken with a telescope, in the colour pages, at the end of the Appendix. Notice the reddish colour of Betelgeuse (nearest the space telescope) and the blue-white colour of the three stars comprising Orion's belt (the ones closest together in a vertical line).

In the previous section you analysed several properties of light, such as propagation, reflection, refraction, diffraction, and interference. You studied how these properties reveal important information about stellar objects.

In this section you will first investigate how another property of light—colour—can be used to classify all stellar objects. Then you will establish how stars are born, and finally you will analyse the life cycle of a star.

Activity 1: Colour of Stars

Perhaps the most aesthetic experience amateur astronomers can have occurs when they first view the heavens through a telescope. The myriad of colours stuns the imagination. Betelgeuse, in the constellation Orion, appears reddish. Sirius, the brightest star in the night sky, is bluish. Other stars are yellow. In fact, every type of star has its own distinct colour.

Why do different stars emit different colours? What additional information about the stars can be revealed from colour?

Although Galileo and the early astronomers all observed the phenomenon of colour, the importance of colour remained a mystery until the early 1900s.

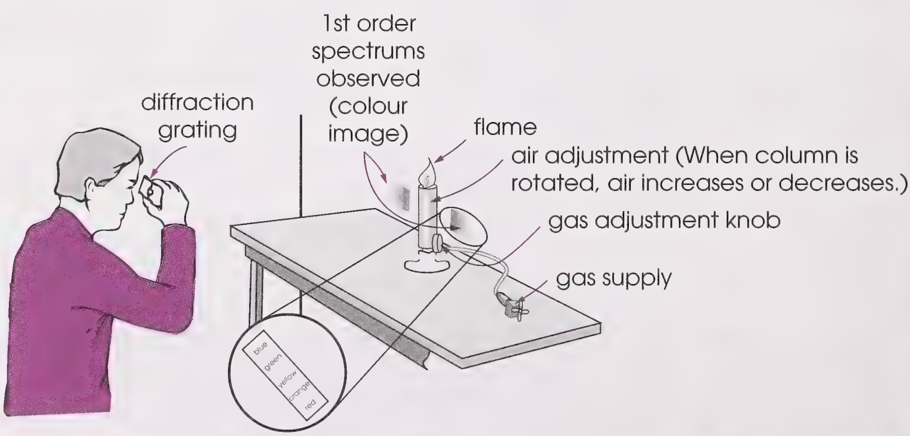
At the beginning of the century a venturesome scientist, Max Planck, proposed an interesting theory that provided the key to unlocking the mystery of the colour of stars. His work initially began with a very simple observation of glowing objects, similar to the following scenario.

Study the following scenario and answer the questions that come after.

Scenario: Observation of a Bunsen Burner Flame

Description

The flame in a Bunsen burner can be adjusted by increasing or decreasing the air-to-gas mixture. When the air-to-gas mixture is slowly increased, changes in the resulting flame can be viewed through a diffraction grating.



Observation

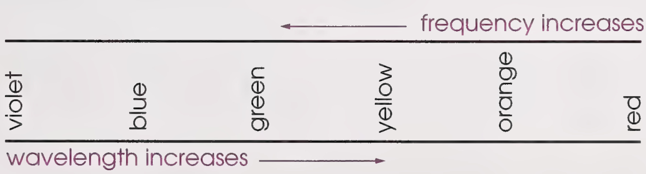
- With the air-to-gas mixture at its lowest, the dominant colour observed in the spectrum is red.
- As the air-to-gas mixture is slowly increased, the dominant colour in the spectrum of the resulting flame, gradually changes to orange, yellow, green, and blue.

1. How will the amount of air in the air-to-gas mixture affect the combustion of the gas?
2. How will an increase in the combustion of the gas affect the temperature of the flame?
3. If the temperature, T, of a substance is a measure of the average kinetic energy, E, of its vibrating molecules, will the energy in the flame increase or decrease as its temperature rises?

DID YOU KNOW?

The actual relationship between energy and temperature is $E \propto T$. (Energy varies directly as temperature varies.)

4. If the energy in the flame is now emitted as visible light, which colour emission corresponds to the lowest energy emission and thus the lowest temperature?
5. Which flame colour emission corresponds to the highest energy emission and thus the highest temperature?
6. Study the following spectrum.



What is the relationship between the energy of the light emitted and the frequency of the light?

Check your answers by turning to the Appendix, Section 2: Activity 1.

The results of the scenario suggests that as the temperature of a glowing object increases, the amount of energy emitted increases, thus emitting a different dominant frequency of light. The initial hypothesis seems to suggest the following relationship for energy and frequency of emitted light.

$$E \propto f$$

(Energy varies directly as frequency varies)

Planck investigated this phenomena more closely and although his final results laid the foundation for a new theory called the Quantum Theory (which is beyond the scope of this course), the resulting idea is a basic understanding of the colour of glowing objects.

The basic theory is that the different colour of stars indicates that they have a different surface temperature. Using this idea, Annie Cannon (1863–1941), an American astronomer at Harvard Observatory, was able to classify over 300 000 stars in the sky.

To understand how this classification was accomplished, study the following table and answer the questions that follow.

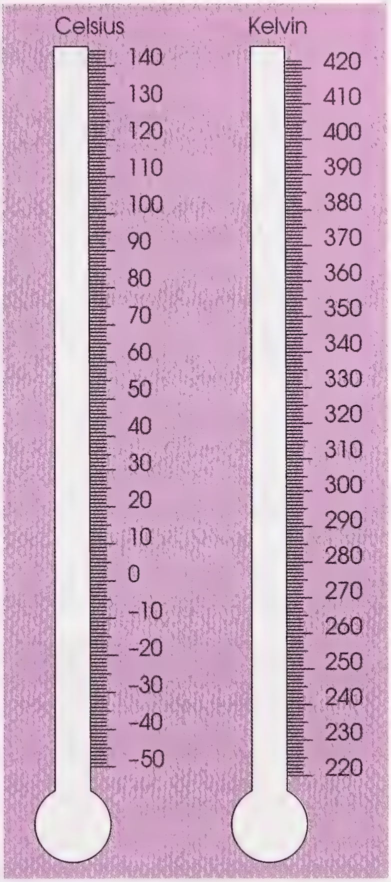
Class	Colour	Effective Temperature (K)	Elements Present in Spectra	Examples of Stars
O	blue	28 000–50 000	He II; He I	<chi> Per, Alnilan, <epsilon> Orion
B	blue-white	9 900–28 000	He I; H	Rigel, Spica
A	white	7 400–9 900	H	Vega, Sirius
F	yellow-white	6 000–7 400	metals; H	Procyon
G	yellow	4 900–6 000	Ca II; metals	Sun, Risil, Kentaurus, <alpha> CenA
K	orange	3 500–4 900	Ca II; Ca I; others	Arcturus
M	orange-red	2 000–3 500	TiO; Ca I; others	Betelgeuse
R	orange-red	3 500–5 400	CN; C_2	—
S	orange-red	2 000–3 500	ZrO; others	R Cyg
N	red	1 900–3 500	C_2	R Lep

7. a. What is the surface temperature range of a typical red star?

   Note that temperatures are given in K, using the Kelvin temperature scale. A comparison of the Kelvin scale and Celsius scale is shown on the right.

   b. To what class does a red star belong?

   c. Give an example of a class N star.



8. a. What is the surface temperature range of a typical blue star?

   b. To what class does a blue star belong?

   c. Give an example of a class O star.

9. To what class does the sun belong?

10. As stars get hotter, what is the most dominant element present?

Check your answers by turning to the Appendix, Section 2: Activity 1.

In this activity you have learned that the colour of a star indicates its surface temperature. However, the answer to why different stars have different temperatures is still to come.

Activity 2: Luminosity of Stars

Not only do stars differ in the colours they emit, they also appear to differ in brightness. Looking directly into the sun is extremely dangerous because its brightness will cause permanent eye damage. Yet, the sun is not the brightest object in the sky. Acturus, a giant star, is actually 105 times brighter than the sun and Betelgeuse, a red supergiant, is 54 000 times brighter.

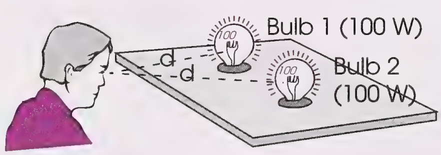
In the previous activity you learned how the colour of a star can be used to classify stars. In this activity you will analyse the factors that influence the brightness of stellar objects and how the brightness of stars can be used to further classify them.

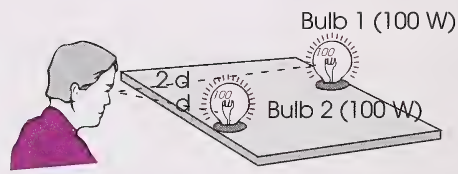
In Activity 1 you learned that a heated object will emit energy in the form of radiation and that the frequency of the emitted radiation depends on the amount of energy emitted. Hence, a star is visible because one of the radiations it emits is in the form of visible light. But what factors determine the **brightness** of this visible light?

brightness – the visual perception of how strong the light from an object is

One factor that influences brightness is depicted in the following situation. Analyse the situation carefully and answer the questions that follow.

Situation 1	Situation 2
Suppose you were standing a certain distance away from two lamps, each with 100 W bulbs.	Now, suppose one of the bulbs was moved twice the distance away from you.



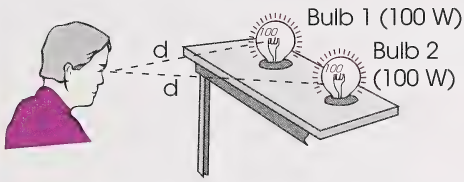
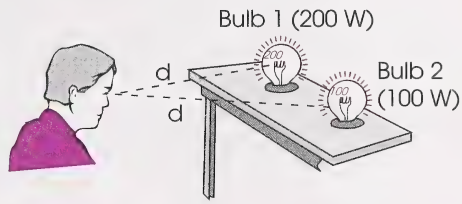


1. Which bulb would appear brighter in Situation 1?

2. Which bulb would appear brighter in Situation 2?

3. Based on the preceding situations, what is one factor that affects brightness?

Another factor that affects brightness is depicted in the next situations. Analyse these situations carefully; then answer the questions that follow.

<table>
<tr><th>Situation 1</th><th>Situation 2</th></tr>
<tr><td>Suppose you were standing a certain distance away from two lamps, each with 100 W bulbs.

</td><td>Now, suppose one of the bulbs was replaced by a 200 W bulb.

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4. In Situation 1, which bulb would appear brighter?

5. In Situation 2, which bulb would appear brighter?

6. Based on the preceding situations, what is another factor that affects brightness?

Check your answers by turning to the Appendix, Section 2: Activity 2.

The power rating of a bulb is given in wattage such as 100 W or 200 W, and it depicts the amount of electric energy (in Joules) consumed by a bulb every second. This electric energy heats up the bulb filament and is converted to light energy which is emitted. The amount of light energy emitted per second by a source is called the **luminosity** of the source.

luminosity – the amount of light energy emitted by a source per second

7. Based on the preceding situations, does a 100 W bulb or a 200 W bulb have a greater luminosity?

Check your answers by turning to the Appendix, Section 2: Activity 2.

The perceived brightness of a star must depend on the luminosity of the star as well as the distance to the star. This explains why some stars are brighter than others, and why scientists are able to further classify stars according to their brightness and luminosity as shown in the following table.

Brightest stars	Distance (light-years)	Temperature (Kelvin)	Visual magnitude	Luminosity (sun = 1)
Sirius A	8.7	10 400	− 1.43	23.0
Canopus	100.0	7 400	− 0.72	1 500.0
Arcturus	36.0	4 500	− 0.06	110.0
Alpha Centauri A	4.3	5 800	− 0.01	1.5
Vega	26.0	10 700	+ 0.04	55.0
Capella	47.0	5 900	+ 0.05	170.0
Rigel	800.0	11 800	+ 0.14	40 000.0
Procyon A	11.3	6 500	+ 0.38	7.3
Betelgeuse	500.0	3 200	+ 0.41	17 000.0

It is important to understand when using the preceding table that negative visual magnitudes indicate brighter stars while positive visual magnitudes indicate dimmer stars. The dimmest object you can detect with your eye is about +6.00. It is also important to understand that the reason why Rigel, which has a luminosity 40 000 times the luminosity of the sun, has a visual magnitude less than Sirius A, which has a luminosity of only 23 times the luminosity of the sun, is because Rigel is so much farther away from Earth than Sirius A.

Now analyse the preceding table and then answer the following questions.

8. What is the luminosity of the star Rigel?

9. What is the luminosity of Rigel compared to?

10. The brightness of a star is displayed as the visual magnitude. Which star is the brightest according to the table?

Check your answers by turning to the Appendix, Section 2: Activity 2.

The most important outcome of classifying stars arose when two astronomers, Hertzsprung and Russell, plotted the luminosity of stars against the temperature of the stars. The resulting graph was called the H-R Diagram. See the colour pages at the end of the Appendix for the H-R Diagram.

Analyse the H-R Diagram and then answer the following questions.

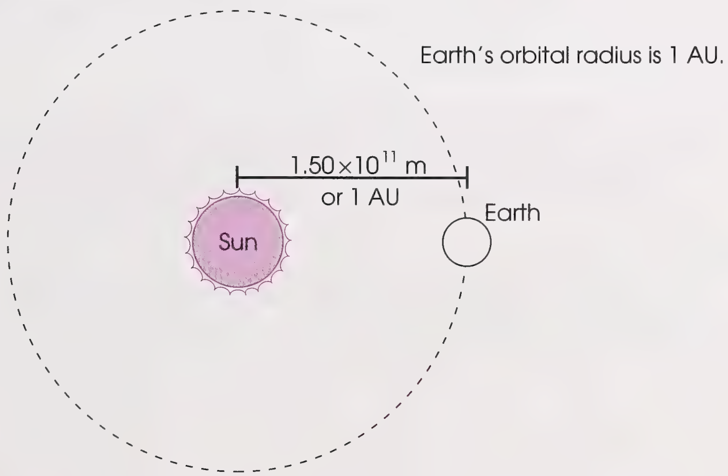
11. a. Complete the following chart to explain what happens to each of the factors as you move horizontally from left to right on the H-R diagram.

Factor	Explanation
• Temperature of the stars	
• Dominant spectrum colour of the stars	

b. Complete the following table to explain what happens to each of the factors as you move vertically from bottom to top on the H-R diagram.

Factor	Explanation
• Brightness or visual magnitude of stars	
• Size of stars	

Because most stars are so large, their size is usually given in Astronomical Units (AU) where one Astronomical Unit is the distance from Earth to the sun. The following diagram shows an Astronomical Unit.



12. a. If the diameter of Betelgeuse is 7 AU, what is the relation of its size to the diameter of Earth's orbit?

    b. Calculate the diameter of Betelgeuse in metres.

It is hard to imagine the immense size of Betelgeuse. The diameter of the orbit of Mars is only about 3 AU while the diameter of Jupiter's orbit is about 10 AU. Thus, if placed with its centre at the centre of the the sun, Betelgeuse would span well beyond the orbit of Mars. Earth would be well within the interior of Betelgeuse if this star were placed with its centre at the sun.

13. The H-R diagram seems to group the stars along three major patterns. Match the name of the pattern with its appropriate position on the diagram.

• Main Sequence Stars	• a pattern of stars along a line near the top of the diagram
• Giant Stars	• a pattern of stars along a line near the middle of the diagram
• Dwarf Stars	• a pattern of stars along a diagonal line near the bottom of the diagram

14. Locate the main sequence stars and complete the questions that follow.

    a. Which part of the main sequence contains the hottest and brightest stars?

    b. Which part of the main sequence contains the coolest and dimmest stars?

    c. Which part of the main sequence would contain blue stars?

    d. Which part of the main sequence would contain red stars?

    e. Where is the sun?

Check your answers by turning to the Appendix, Section 2: Activity 2.

In this activity you studied the factors that affect the brightness of stars and you are able to distinguish dwarf, giant, and main sequence stars. In the next activity you will follow the life cycle of a star.

Activity 3: Life Cycle of Stars

LOS ALAMOS NATIONAL LABORATORY

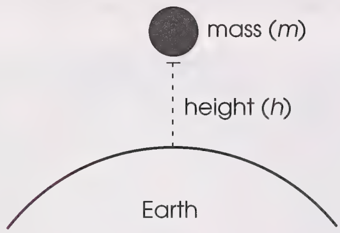
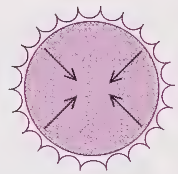
The sun has often been compared to a hydrogen bomb. What is the similarity between the sun and a hydrogen bomb? The obvious answer is that both have vast amounts of energy, but there is a more important similarity.

This important similarity was not discovered until scientists began to probe for answers to the following questions.

- What is the source of energy in the stars?
- Why do different stars emit different kinds and amounts of energy?
- Why are some stars different than others?

In this activity you will learn the answers to these questions and you will discover the similarity between the sun and a hydrogen bomb.

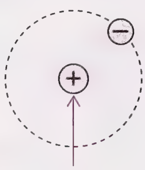
Historically, the first rational attempt to explain the source of energy in the sun or any star was initiated by Kelvin and Helmholtz in the 1800s. Using the ideas of gravity and potential energy, they proposed that a collapsing or contracting star (due to the intense forces of gravity) would result in a dramatic loss of gravitational potential energy which would be converted to heat. This process is explained in the following diagrams.

Earth's Gravitational Potential Energy	Sun's Gravitational Potential Energy
	
Any mass above the surface of Earth has gravitational potential energy due to Earth's forces of gravity. If the object falls to Earth it loses this potential energy to other forms of energy.	The sun is a huge ball of gases which can collapse into the centre. This fall of gases results in a similar loss of gravitational potential energy to other forms of energy.

Since the amount of energy in the sun is so large, scientists felt that gravitational potential energy cannot be the only source of energy. Therefore, scientists searched for other explanations for the source of energy in the sun.

Another theory, presented by Einstein in 1905, actually began from a revolutionary idea that matter itself can be converted into pure energy. Could this be the source of energy on the sun?

Scientists began to investigate this matter-to-energy conversion reaction and by 1932 had uncovered some startling discoveries. To fully understand these discoveries, begin with the Rutherford-Bohr model of the hydrogen atom of the early 1900s as shown in the following chart.

Rutherford-Bohr Model of the Hydrogen Atom	Fundamental Particles of the Hydrogen Atom	Chemical Symbol of the Hydrogen Atom from the Periodic Table
 An electron in orbit around the nucleus as predicted by Bohr Minute nucleus containing one positive charge called a proton as predicted by Rutherford	1 Hydrogen (H) atom has 1 electron (e^-) 1 proton (p^+)	atom mass, A (denotes the number of particles in nucleus) $^{1}_{1}H$ atomic number, Z (denotes the number of e^- or p^+)

Because all atoms of elements were thought to contain these same fundamental particles, the ultimate questions arose.

Could it be possible to fuse or join nuclei together to create bigger atoms? Could hydrogen nuclei be fused together to form the next heavier element helium?

Einstein predicted this could happen and the result would not only be a net loss of mass but a drastic release of new energy, according to the following equation.

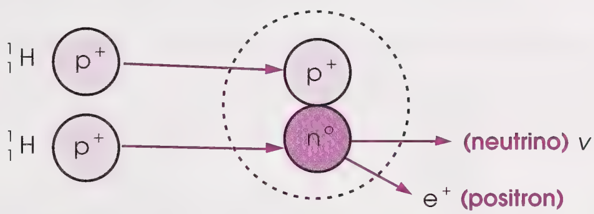
$$\Delta E = \Delta m c^2$$

- c^2 — speed of light squared, $c = 3.00 \times 10^8 \ \frac{m}{s}$
- ΔE — energy equivalent of the loss in mass in joules
- Δm — change in mass in kilograms

The process of fusion and the subsequent production of energy also predicted the formation of other fundamental particles. To analyse this process, study the step-by-step descriptions and answer the questions that follow. These steps need not be memorized but will give you an understanding of how a nuclear reaction occurs.

Step 1: Production of a Deuteron Atom

Although the two positive nuclei normally repel, each due to the electrostatic repulsive forces as determined by Coulomb, it was suggested that at high temperatures (over 1 million K) the two protons have enough energy and speed to tunnel through the repulsive forces and stick together causing nuclear attractive forces.



Upon fusion one proton ejects its positive charge as a new particle called a positron (e^+) and a neutrino. This leaves a nucleus with a particle similar in mass to a proton, but with no charge called a **neutron** (n^o). The combined nuclei is called a deuteron which is a heavier hydrogen nucleus because of the added neutron $\left(^2_1H\right)$.

neutrino – a particle with no mass and no charge

positron – a particle similar to an electron but with a positive charge

neutron – a particle with the same mass as a proton but with no charge

Note: Even though scientists predicted the existence of these new particles, they were not actually discovered until many years later—deuteron, neutron, positron in 1932 and the neutrino in 1956.

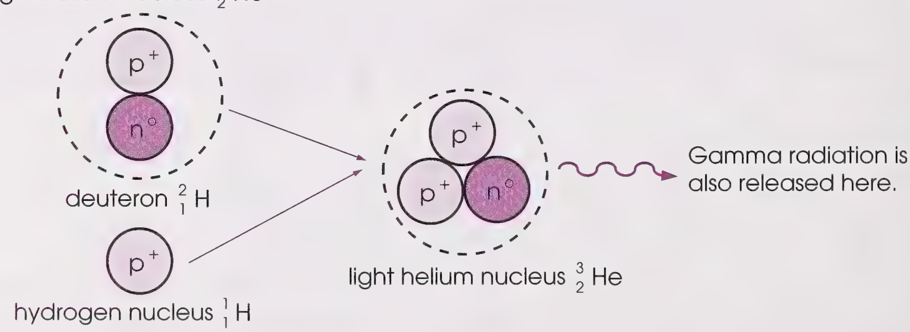
1. Initially you learned that there were only two fundamental particles. Now, in order for Step 1 to occur, other particles were predicted to exist. To compare all the fundamental particles, complete the following table.

Fundamental Particle	Symbol	Charge (C)	Mass (kg)
Electron	e^- or ${}^{0}_{-1}e$	-1.60×10^{-19} C	9.11×10^{-31} kg
Proton	p^+	$+1.60 \times 10^{-19}$ C	1.67×10^{-27} kg
Neutron			
Deuteron			
Neutrino			
Positron			

Step 2: Production of Light Helium

The positron, e^+, called an antiparticle cannot exist and immediately reacts with an electron e^-, destroying their mass and producing energy in the form of gamma radiation.

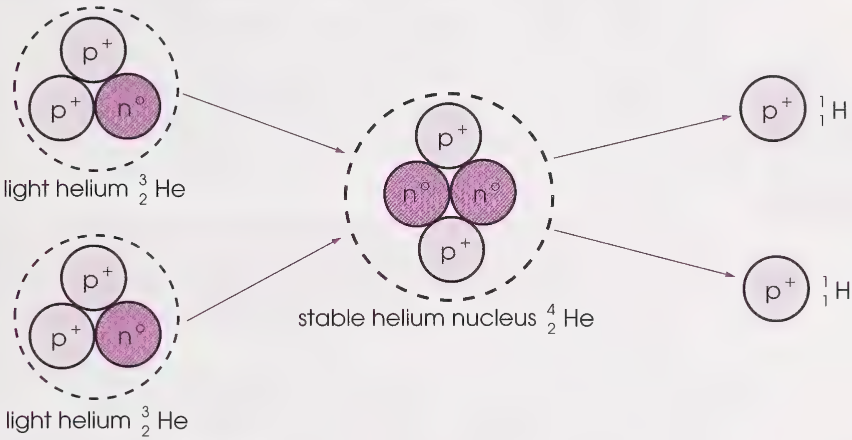
The deuteron ${}^{2}_{1}H$ immediately reacts with another hydrogen nucleus ${}^{1}_{1}H$ to produce light helium nucleus ${}^{3}_{2}He$.



2. This step results in the production of energy as gamma radiation. Describe two processes that produce gamma radiation.

Step 3: Production of Helium

Two light helium ${}^{3}_{2}He$ immediately fuse to form a stable helium nucleus ${}^{4}_{2}He$ and releases two positive charges as stable hydrogen nuclei ${}^{1}_{1}H$.



Nuclear change within the sun can be represented by the following equations.

$${}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}He + {}^{1}_{0}n \quad \text{and} \quad {}^{3}_{2}He + {}^{3}_{2}H_{e} \rightarrow {}^{4}_{2}He + {}^{1}_{1}H + {}^{1}_{1}H$$

3. How many times must Step 2 occur before Step 3 can occur?

Check your answers by turning to the Appendix, Section 2: Activity 3.

Although this fusion reaction involves three steps, these steps all occur almost instantaneously. The startling discovery was that since 1 helium nucleus can be created by the fusion of 4 hydrogen nuclei, then the conservation of mass law predicts that

1 He nucleus mass = 4 H nuclei masses

But in reality the transformed He nucleus will be 0.07% lighter. Where did this loss of mass go?

Einstein's prediction is right! This loss in mass is converted to pure energy according to his equation.

4. If the loss in mass in the creation of one He nucleus is 4.68×10^{-28} kg, how much energy will be created?

In order for this hydrogen fusion reaction to be considered as a possible source of energy on the sun, it has been estimated that the actual solar output of energy would require the conversion of 6.0×10^{11} kg of H atoms to stable He atoms every second.

Visions

5. At this rate of conversion do you think the sun has enough hydrogen atoms to continue fusion for billions of years? Use the provided rate of conversion and the mass of the sun as given on page 326 of *Visions 3* to calculate how long the sun could last at this rate of fusion.

Check your answers by turning to the Appendix, Section 2: Activity 3.

With the development of the hydrogen bomb by 1945, the possibility of hydrogen-to-helium fusion as a tremendous source of energy was confirmed. As the investigations into nuclear fusion advanced, it was noted that at higher temperatures (15 000 000 K) carbon-to-nitrogen fusion can occur, and at still higher temperatures even larger atoms may fuse, all with the release of tremendous amounts of energy. This must be the source of energy in the sun and other stars!

Visions

To review these processes read pages 324 and 325 of your text, then complete the following chart.

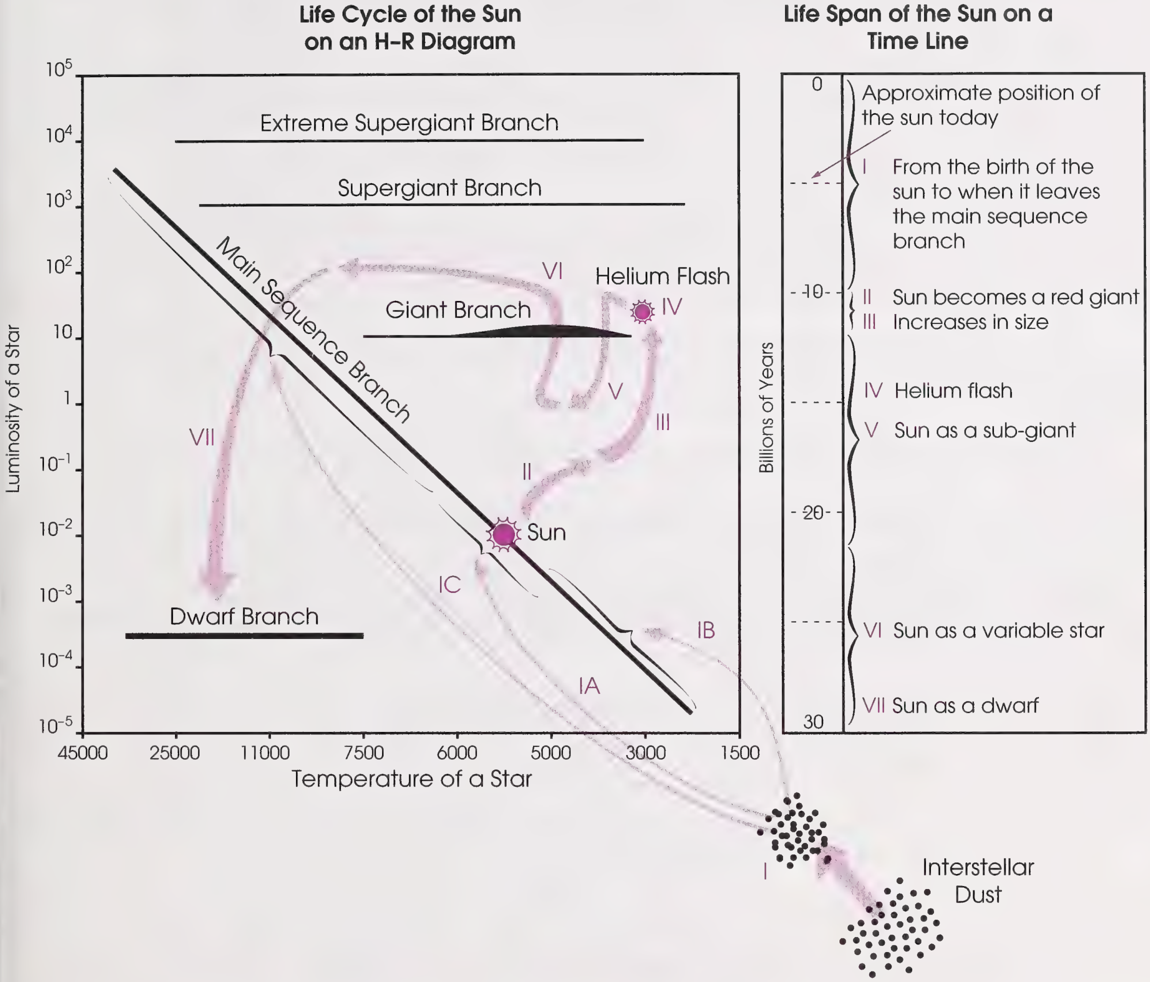
6.

Source of energy	Temperature at which each source of energy can occur
	• below 1 000 000 K
	• between 6 000 000 K and 16 000 000 K
	• above 15 000 000 K

Check your answers by turning to the Appendix, Section 2: Activity 3.

The major source of energy in all stars is the nuclear fusion reaction and the subsequent conversion of mass into energy. This can explain why all stars are different, since different reactions occur at different times in the life cycle of a star.

Using the H-R diagram follow the life cycle of a star. Follow the numbered path (I, II, III, IV, V, VI, VII) on the diagram and study the following explanations to analyse the birth and the eventual death of the most important star, the sun. After you have analysed the life cycle and life span of the sun, answer the questions that follow.



I. All stars start from swirls of interstellar dust that slowly pull together from the forces of gravitational attraction. As they compress, their temperature increases until fusion begins and the star begins its life on the main sequence branch. The position at which a star enters the main sequence branch depends on the initial mass of the star as described.

IA – if the mass of the star is comparable to the mass of the sun, (given as $M_{\odot}$)
IB – if the mass of the star is much less than the mass of the sun
IC – if the mass of the star is much larger than the sun

II. Eventually the hydrogen for fusion in the core is exhausted, but fusion in the outer shell continues. Luminosity remains the same, but without the core, gravity collapses and the shell begins to expand with a drop in temperature.

III. Dramatically the sun will suddenly increase to 100 times its size and become 1000 times brighter as it becomes a red giant.

IV. The outer hydrogen shell continues to expand, but the inner helium core compresses drastically causing a violent explosion called a helium flash.

V. The sun achieves stability and drops to a sub-giant.

VI. Helium fusion begins in a shell around the core increasing luminosity and temperature and hydrogen fusion in the outer shell switches on and off creating a variable star.

VII. All fuel burns out and fusion stops, leaving a dense core called a dwarf.

7. a. What is the approximate age of the sun?

   b. How much longer will it remain as it is today?

8. Eventually the sun will reach its final stage as a dwarf. In approximately how many years will this occur?

9. The sun will go through many stages in its life cycle. Write the stages in proper order.

present sun	interstellar dust
sub-giant	dwarf
red giant	variable star

10. During which stage or stages on the H-R diagram will the sun be able to sustain life on Earth?

11. Do you think the sun could ever become a supergiant? Explain.

12. Do you think all stars follow the same life cycle? Explain.

Visions

The life cycle and the life span of a star depends on its initial mass, which is its fuel supply, and its rate of fuel consumption. A logical conclusion would be that the greater the initial mass, the longer the life span of a star. In actual fact, the opposite is true. Read pages 326 and 327 of *Visions 3*, study the following table, and answer the questions.

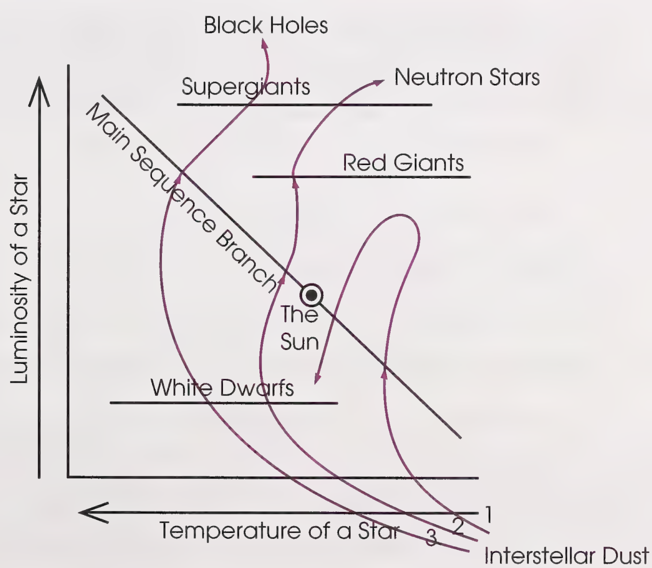
RELATIONSHIP OF LIFE SPAN OF STARS AND THEIR MASS		
Mass of Star Compared to the Mass of the Sun ($M_\odot$)	**Life Span of the Star as a Fraction of the Sun's Life Span**	**Life Span of the Star in Approximate Years (a)**
Mass of Star = 0.8 $M_\odot$	300	9 000 000 000 000 a
Mass of Star = $M_\odot$	1	30 000 000 000 a
Mass of Star = 2.5 $M_\odot$	$\frac{1}{10}$	3 000 000 000 a
Mass of Star = 10 $M_\odot$	$\frac{1}{300}$	100 000 000 a
Mass of Star = 100 $M_\odot$	$\frac{1}{10\ 000}$	3 000 000 a

Note: None of the stars with a mass 0.8 $M_\odot$ or less have ever gone through a complete life cycle.

13. What appears to be the relationship between mass of a star and its life span?

14. Why do you think the relationship is such?

15. Beginning with interstellar dust and gases called nebula, the life cycle of a star can follow different paths. The following is an H-R diagram depicting three possible paths. Study the diagram and answer the questions that follow.



a. What factor determines if the evolving star follows path 1, 2, or 3?

b. What factor determines if an evolving star becomes a neutron star or a black hole?

Check your answers by turning to the Appendix, Section 2: Activity 3.

In this activity you have studied the factors that determine the type of star seen in the sky and you have analysed how the star was born, its life cycle, and its eventual death.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

1. The colour of a star reveals some important data about that star.

   a. What is the colour of the sun?

   b. What does this colour indicate about the sun?

   c. What is the approximate temperature of the sun?

2. What two factors affect the brightness of a star?

3. a. What is the unit for measuring star distance?

   b. What is the unit for measuring star size?

   c. What is the unit for measuring star mass?

4. The source of energy for stars along the main sequence branch is nuclear fusion or the proton-proton chain involving the fusion of hydrogen into helium.

   a. Write the symbol for each particle involved in this nuclear fusion reaction.

hydrogen atom	neutrino
deuterium atom	gamma radiation
light helium atom	positron
helium atom	electron

b. What is the difference between a $^{1}_{1}H$ and a $^{2}_{1}H$?

c. What is the difference between a $^{3}_{2}He$ and a $^{4}_{2}He$?

d. Initially you studied that the fundamental particles in the atom were an electron, a proton, and a neutron. Name three other particles you have now studied.

Check your answers by turning to the Appendix, Section 2: Extra Help.

Enrichment

Do one or more of the following questions.

1. Neutrinos have no mass and no charge. How are these particles detected? Research this topic in your local library or in a university library and write a one-page report discussing how they were first detected.

2. Do a library research topic on either black holes or the creation of supernovae. In your research discuss

   - how they are created
   - one example of where they have been spotted in the universe
   - their impact on theories of the universe

Check your answers by turning to the Appendix, Section 2: Enrichment.

Conclusion

In this section you discovered how another property of light (colour) reveals important information about stars, and you also analysed how stars are born and evolve into the myriad of phenomena that astronomers find when viewing the night-time sky.

In the next section you will study the theories that explain how the universe began.

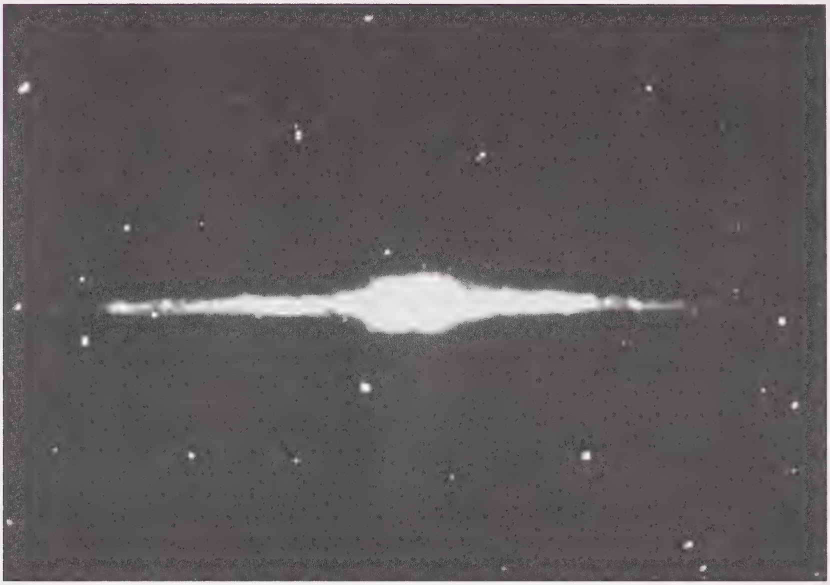
Assignment Booklet

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 2.

Section

3 Where Did It All Begin?



NASA

If you look straight upward into the night sky you can see thousands of stars scattered throughout the sky; there is a blurry band running across the sky from east to west. The photograph above shows a computer imaging of this band taken by COBE (Cosmic Background Explorer), a satellite launched in Novermber 1989.

The ancient Chinese called this band a Celestial River and the early North American Indians called it a White River. The Europeans in the first century AD thought this band marked a seam where the two halves of heaven were joined.

What is this river of blurry light? What secrets can it reveal about the universe?

In this section you will discover the secrets of the photograph and you will study how these secrets enabled scientists to formulate a theory of how the universe began.

Activity 1: Doppler Effect

As technology in astronomy improved scientists were able to look deeper and deeper into the secrets of the universe and gradually many remarkable discoveries were made. In this activity you will analyse some of these discoveries and you will see how they revealed an overall picture of the universe.

The first remarkable discovery concerned the blurry band of light running across the sky. In actual fact this Celestial River was a cluster of many stars called the Milky Way Galaxy. This galaxy is thought to be similar in shape to the one shown in the following photograph.

Like the galaxy picture on the right, the Milky Way Galaxy is a cluster of over 400 billion stars in spiral rotation around a central hub. The Milky Way Galaxy has a diameter of 100 000 light-years and includes the sun, which lies about $\frac{3}{5}$ of the distance from the centre in one of the spiral arms.

NASA

This observation shattered the ancient theory that all stars were located the same distance from Earth and calculations of the distances proved to be of astronomical values. Earth's nearest stellar neighbour, Alpha Centauri, is 4.3 light-years away, or 4.07×10^{13} km!

DID YOU KNOW?

If you travelled in a spaceship at a speed of 30 000 km/h, it would take you about 155 000 a to reach Alpha Centauri.

Another startling discovery was that what appeared to be a blurry star in the upper left of the Andromeda constellation was actually another cluster of billions of stars called the Andromeda Galaxy. The galaxy in the previous photograph is the Andromeda Galaxy. This galaxy is over 2 000 000 light-years away.

Other galaxies were eventually discovered and scientists realized that galaxies also appear to cluster together as groups. The Milky Way Galaxy is clustered with seventeen other galaxies in what is called the Local Group.

One thing you must realize is that although relative to the universe as a whole these 17 galaxies in the local group are clustered together, the distances between each galaxy in this group is still immense.

As astronomers peered deeper and deeper into space, another startling discovery was made concerning the light reaching Earth from these distant stars. If it takes 2 000 000 years for light to reach Earth from Andromeda, then events that occurred 2 000 000 years ago in Andromeda are being observed here today.

As you look deeper into space, the farther back in time you go!

1. If it could be possible to look so deep into space that the light observed occurred at the beginning of time, what might this light reveal?

Check your answers by turning to the Appendix, Section 3: Activity 1.

The next piece in assembling the puzzling model of the universe was discovered when scientists began to study the motions of the galaxies in relation to each other.

Visions

To understand the motions of all the galaxies in the universe read page 340 of *Visions 3* and answer the following questions.

2. The textbook compares the universe to a physical raisin bread model.

   a. What does the dough represent?

   b. What do the raisins represent?

   c. If the Milk Way Galaxy is represented by one of the raisins and other galaxies by the remaining raisins, how are all the other galaxies moving in relation to us?

   d. Are all other galaxies moving at the same speed?

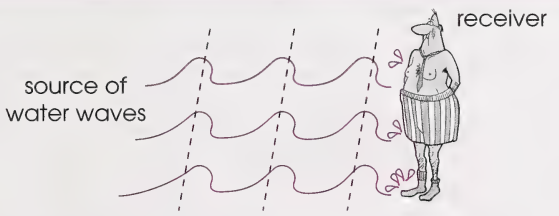
   e. What factor seems to determine the speed of the galaxies as represented by raisins?

3. This raisin bread model led scientists to theorize that galaxies in the universe behave in a similar fashion. What type of universe is this called?

Check your answers by turning to the Appendix, Section 3: Activity 1.

Doppler effect – the apparent change in frequency of a wave due to the motion between a source and a receiver

Experimental proof of the differing motions of the galaxies resulted from studies of a property of all electromagnetic waves called the **Doppler effect**. To understand this effect study the following scenario and answer the following questions.

Scenario of a Person (Receiver) in a Water Wave Pool	
	Suppose you were standing in a stationary position in a wave pool. The waves would splash against you (receiver) with a certain frequency set by the wave source at one end.

Now, imagine you were walking towards the wave source generator.

4. a. Would the waves appear to splash against you at a faster rate?

   b. What appears to have happened to the frequency of the waves?

   c. Has the frequency of the waves really changed?

   d. What conclusion can you make concerning the apparent change in frequency as a receiver moves towards a source?

Now, imagine you are walking away from the wave source generator.

5. a. Would the waves appear to splash against you at a slower rate?

   b. What appears to have happened to the frequency of the waves?

   c. What conclusion can you make concerning the apparent change in frequency as a receiver moves away from a source?

Check your answers by turning to the Appendix, Section 3: Activity 1.

This apparent change in frequency due to the motion between a source and a receiver is called the Doppler effect and is true for all waves, including sound and light waves. This effect was used by Edwin Hubble (1889–1953) to explain the motions of stars.

Visions

Read pages 341 and 342 of your textbook and answer the following questions.

6. a. If a star (the light source) was moving rapidly away from you (the receiver), what would appear to happen to the frequency of the light from the star?

   b. How would this motion appear to affect the wavelength of the light from a receding star?

   c. What is this shift called? Why?

   d. What is the relationship between this redshift and the speed of the receding star?

   e. What is the relationship between the speed of the receding star and its position in the universe?

7. a. If a star were rapidly approaching you, what would appear to happen to the frequency of the light reaching you from the star?

   b. How would this motion affect the wavelength of the light reaching you?

   c. What might this shift be called?

8. Study Photo 10.7 on page 343 of *Visions 3*. The photograph shows the redshifts for clusters of galaxies located in various constellations. Answer the following questions about the redshifts or what this redshift reveals about the galaxy.

   a. Which galaxy cluster has the greatest redshift?

   b. Explain why it has the greatest redshift?

   c. Which galaxy cluster appears to be the largest?

   d. Why does it appear to be the largest?

Check your answers by turning to the Appendix, Section 3: Activity 1.

The current model of the universe seems to include billions of galaxies that are rapidly moving away from each other creating an expanding universe. Within each galaxy are billions of stars, all moving in circular tracks around a central hub. Evidence provided by the Doppler shifts have proved that the universe is expanding. In addition, Hubble's conclusions that the more remote a galaxy is from the Milky Way Galaxy the faster it is moving, still holds true at the present time, even with all the new observations and resulting evidence. In other words the speed of each galaxy depends on its distance from the observer (the farther away a galaxy is, the faster it is moving).

Hubble hypothesized that if the speed and the distance to various galaxies could be determined, then by using the following equation he could determine an average value for the time that each galaxy has been travelling.

$$\text{Since:}\quad \underbrace{v}_{\text{speed of galaxy (m/s)}} = \frac{\Delta d \longrightarrow \text{distance to galaxy (m)}}{\Delta t \longrightarrow \text{time of travel (s)}}$$

$$\text{then}\quad \boxed{\Delta t = \frac{\Delta d}{v}}$$

Use this formula to calculate the time it takes for light from the galaxy given in the following question to reach Earth.

9. If it was determined that the speed of a galaxy was 70 km/s and the distance away from Earth was 3.262×10^{6} light-years away, find the time it takes light to reach Earth from that galaxy in

   a. seconds

   b. years

Check your answers by turning to the Appendix, Section 3: Activity 1.

The results were astounding. After several calculations using data from different galaxies, Hubble determined that the average values of the times of travel for all galaxies was roughly the same value of 1.4×10^{10} years. If all galaxies have been travelling for this time, then they must have all started from the same place at the same time. This would be the time that the universe began.

Using an average value of 70 km/s/Mpc for the Hubble constant, most scientists calculate the age of the universe to be a little more than 14 billion years old. However, if different values for the Hubble constant are used, then the age may vary from as low as 9 billion years to as much as 20 billion years.

In the next activity you will study what it is thought may have happened in the first few seconds, over 14 billion years ago, when the universe began.

Activity 2: Beginning of the Universe

Even though astronomers throughout the ages have made exciting discoveries to explain many of the phenomena in space, there is one intriguing phenomena that still challenges astronomers today. This phenomena concerns the formation of the universe.

How did it all begin? What happened in those first few moments over 14 billion years ago? Will the universe ever cease to exist or has the universe always been there and always will be?

In this activity you will study the different theories that have been proposed to explain the creation of the universe.

Visions

To study one of the early theories read page 344 of your textbook and then answer the following questions.

1. Name the theory that proposes that there is always the same amount of matter in a given space at a given time.
2. According to this theory, how did the universe begin?
3. At what rate is the universe expanding according to this theory?
4. If the universe is expanding and galaxies are moving away from each other, this would create a void in the middle. What did this theory assume would happen to keep the density of the universe the same throughout?
5. By the 1950s scientific evidence from radio waves began to reveal a serious contradiction in this theory. Discuss this contradiction.

Check your answers by turning to the Appendix, Section 3: Activity 2.

With the rejection of the steady-state theory, scientists began to search for another theory. The big-bang theory appeared to be the most logical and is the accepted theory in the scientific community today.

Visions

To study this theory, read the bottom of page 344 and the top of page 347 of your textbook and answer the following questions.

6. According to the big-bang theory, how did the universe begin?

7. According to this theory how was all the matter in the universe created?

8. When was all this matter created?

9. When were galaxies formed?

10. How is the universe expanding at the present time?

11. State the most significant evidence supporting this theory.

Check your answers by turning to the Appendix, Section 3: Activity 2.

Most scientists thought the universe was formed from one big-bang at one point in space and the resultant creation of matter from the radiation created a universe that has been expanding at an increasing rate for over 14 billion years. Will it continue to expand at such a rate? Scientists believe that there are three possibilities concerning the future of the universe.

Visions

Read page 347 of your textbook and complete the following chart.

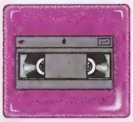
12.

THREE POSSIBILITIES FOR THE FUTURE OF THE UNIVERSE		
Possibility	**Factor that Affects This Possibility**	**Eventual Fate of the Universe**
If the universe is **open**		
If the universe is **closed**		
If the universe is neither **open** nor **closed**		

13. Do Textbook question 6 from the Think section on page 350 of *Visions 3*.

Check your answers by turning to the Appendix, Section 3: Activity 2.

In this activity you have analysed opposing theories as to how the universe began. You theorized that the universe has been expanding for over 14 billion years and is presently expanding. However, whether the universe will continue to expand or whether it will eventually begin to contract and return to a point in space are questions scientists continue to ponder. The real truth is still to be found.



You may wish to watch the video titled *NASA Space: Universe*, ACCESS Network, for an overall review of telescopes and the various phenomena of astronomy. You may be able to obtain this video through your school or local library.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

All scientific evidence indicates that there are billions of stars in each galaxy and that there are billions of galaxies.

1. a. What is the name of our galaxy?

   b. How are all galaxies moving in relation to this galaxy.

   c. What is the estimated age of the universe?

2. a. What effect proves that all galaxies are moving away from us?

   b. What happens to the wavelength of the light reaching us if stars are receding or going away from us?

3. a. What are two opposing theories of the creation of the universe?

   b. Which theory is generally accepted at the present time? Why?

4. Name the three possible theories for the future of the universe.

Check your answers by turning to the Appendix, Section 3: Extra Help.

Enrichment

Do one or both of the following questions.

Visions

1. Do Textbook question 8 from the Think section of page 350 of *Visions 3*.
2. Do Textbook question 1 and 2 from the the Dream section found on page 350 of *Visions 3*.

Check your answers by turning to the Appendix, Section 3: Enrichment.

Conclusion

In this section you studied how scientists gathered data and performed calculations to propose two opposing theories of the beginning of the universe itself and to suggest some possible fates of the universe in the end. But as you have seen, this study is still emerging and very little is certain.

Assignment Booklet

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 3.

MODULE SUMMARY

In this module you were introduced to an exciting branch of science called astronomy. You first studied how scientists use advancing technologies to analyse the various properties of light and other electromagnetic radiation reaching Earth from all parts of the universe. You then analysed how this data was able to be used to formulate theories on the evolution of stars from interstellar nebulae, the myriad of other phenomena you see in the night-time sky, as well as to suggest how the universe possibly began. In the end, you should have realized that there is still much exciting work to be done before the real truth is known.

Appendix

Glossary

Suggested Answers

Colour Diagrams and Photographs

Glossary

amplitude: the maximum displacement of the wave from the equilibrium position

bright-line emission spectrum: a spectrum in which only a few distinct colour lines are observed

brightness: the visual perception of how strong the light from an object is

constructive interference: the result of two waves adding together

continuous spectrum: a spectrum in which all the colours of the visible spectrum are observed, similar to a rainbow

dark-line absorption spectrum: a spectrum in which all the colours are observed with a few distinct dark lines

destructive interference: the result of a crest and a trough cancelling each other partially or completely

diffraction grating: a transparent filter with multiple slits (i.e., 2000 slits/cm)

Doppler effect: the apparent change in frequency of a wave due to the motion between a source and a receiver

equilibrium: the rest position of the wave where no net forces act on the wave

geocentric: Earth-centred universe

law of superposition: the amplitude of the resulting wave is determined by adding the displacements of the individual waves superimposing

luminosity: the amount of light energy emitted by a source per second

neutrino: a particle with no mass and no charge

neutron: a particle with the same mass as a proton but with no charge

planar water waves: waves that are travelling in one direction or plane

positron: a particle similar to an electron but with a positive charge

propagation: how light travels from one place to another

spectral fingerprinting: using bright-line emission and dark-line absorption spectra to identify the type of element in a sample

ultraviolet light: electromagnetic radiation with a frequency range of about 8×10^{14} Hz to 3×10^{17} Hz that is responsible for suntanning

visible light: electromagnetic radiation that can be detected by the human eye

x-rays: electromagnetic radiation with a frequency range of about 3×10^{17} Hz to 5×10^{19} Hz, used mainly for medical diagnosis

Suggested Answers

Section 1: Activity 1

1. The Greeks pictured the stars as fixed on the inside of a large inverted rotating sphere.

2. They believed that stars moved in perfect circles around Earth.

3. Early Greek astronomers were Pythagoras, Aristotle, Plato, Aristarchus, and Ptolemy.

4. Aristarchus proposed that Earth moved around the sun.

5. Ptolemy said that Earth was the centre of the universe.

6. Copernicus proposed that the sun was the centre of the universe (heliocentric).

7. Martin Luther opposed this theory; he felt it would disrupt much of what was established about astronomy.

8. Galileo defended the Copernican theory.

9. The new technology was a crude telescope that could show the craters of Earth's moon as well as four moons orbiting Jupiter.

10. The Roman Catholic church opposed Galileo on the basis that this represented an imperfect heaven.

11. Galileo was forced to state that his theory was in error.

12. Three hundred years later, in 1979, the Church finally cleared Galileo's name.

13.
$$v = \frac{\Delta d}{\Delta t}$$
$$\Delta t = \frac{\Delta d}{v}$$
$$= \frac{1.50 \times 10^{11}\ \text{m}}{3.00 \times 10^{8}\ \frac{\text{m}}{\text{s}}}$$
$$= 5.00 \times 10^{2}\ \text{s or } 8.33\ \text{min}$$

14.
$$\Delta t = \frac{\Delta d}{v}$$
$$= \frac{5.75 \times 10^{12}\ \text{m}}{3.00 \times 10^{8}\ \frac{\text{m}}{\text{s}}}$$
$$= 1.92 \times 10^{4}\ \text{s or } 5.32\ \text{h}$$

15.
$$\Delta t = \frac{\Delta d}{v}$$
$$= \frac{5.75 \times 10^{12}\ \text{m}}{1.15 \times 10^{4}\ \frac{\text{m}}{\text{s}}}$$
$$= 5.00 \times 10^{8}\ \text{s or } 15.8\ \text{a}$$

16.
$$\Delta t = \frac{\Delta d}{v}$$
$$= \frac{4.07 \times 10^{16}\ \text{m}}{1.15 \times 10^{4}\ \frac{\text{m}}{\text{s}}}$$
$$= 3.54 \times 10^{12}\ \text{s or } 112\,000\ \text{a}$$

17.
$$1\ \cancel{\text{a}} \times \frac{365\ \cancel{\text{d}}}{\cancel{\text{a}}} \times \frac{24\ \cancel{\text{h}}}{\cancel{\text{d}}} \times \frac{60\ \cancel{\text{min}}}{\cancel{\text{h}}} \times \frac{60\ \text{s}}{\cancel{\text{min}}}$$
$$= 3.1536 \times 10^{7}\ \text{s}$$
$$= 3.15 \times 10^{7}\ \text{s} \ \text{(to 2 significant digits)}$$

18.
$$\Delta d = v\Delta t$$
$$= \left(3.00 \times 10^{8}\ \tfrac{\text{m}}{\text{s}}\right)\left(3.1536 \times 10^{7}\ \text{s}\right)$$
$$= 9.46 \times 10^{15}\ \text{m}$$
$$= 9.46 \times 10^{12}\ \text{km or } 9\,460\,000\,000\,000\ \text{km}$$

19. a. $\dfrac{1\text{ light year}}{9.46\times10^{15}\text{ m}} = \dfrac{n}{4.07\times10^{16}\text{ m}}$

$n = 4.30$ light-years

Alpha Centauri A is 4.30 light-years from Earth.

b. You are not working with such large numbers.

Section 1: Activity 2

1. Because this telescope has lenses, it involves the refraction of light.

2. a. The lens causes light to disperse into colours and is called chromatic aberration.

   b. The lens acts as a prism.

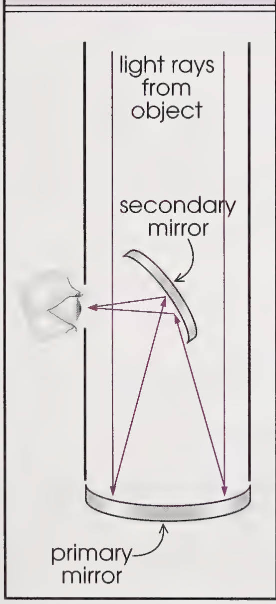
   c. Use a series of compound lenses to correct chromatic aberration.

   d. The largest refracting telescope has a lens 1 m across.

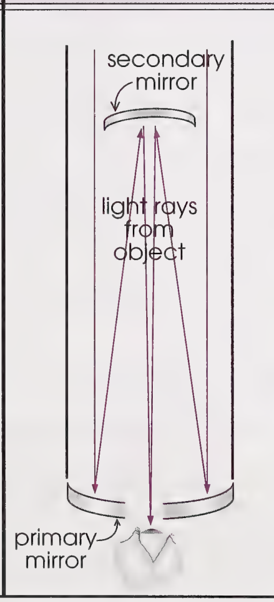
3. Newton's telescope operates on the property of the reflection of light.

4.

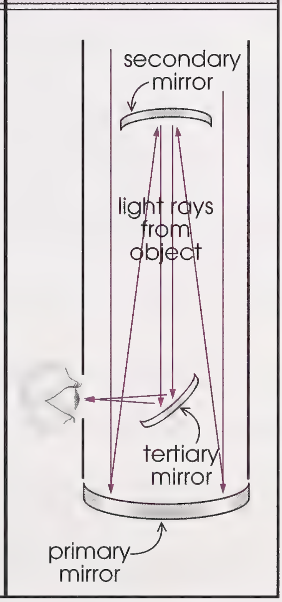
Type 1
Newtonian



Type 2
Cassegrain



Type 3
Coudé



5. A CCD (charge-coupled device) collects images from reflecting telescopes and records them electronically. This electronic file is later analysed by a computer.

6. The atmosphere distorts images from space.

7. Scientists tried to overcome this problem by situating telescopes on high mountains or, more recently, by positioning them in space.

8. The radiations that can reach Earth's surface are visible light and radio waves. The radiations that partially reach the surface of Earth are infrared and ultraviolet.

9. First, radio pulses from space could only be explained as being from rapidly rotating neutron stars called pulsars.

   Second, radio waves could penetrate the gas and dust of the Milky Way Galaxy and allow scientists to map the shape and gas structures of the galaxy.

   Third, radio waves indicated an intense energy source in a small region of the galaxy and suggested the existence of black holes.

10. a. Infrared radiation is emitted by cooler stars.

    b. Infrared radiation reveals interstellar dust the best.

    c. Infrared can pinpoint infant stars as indicated by Plate 10.5.

11.

Type of Radiation	Position in atmosphere where blockage occurs	Substance involved in blocking radiation
Ultraviolet	around 100 km above the surface of Earth	absorbed by ozone
X-ray	above 75 km above the surface of Earth	absorbed by the ionosphere
Gamma	above 30 km above the surface of Earth	absorbed by matter in the atmosphere

12. a. Both x-rays and gamma rays originate from regions in space that are very hot or in which motions are very violent.

    b. X-rays can indicate the existence of black holes.

    c. Black holes are so massive that they do not allow any radiation to escape.

    d. If the movement of a certain star cannot be explained by gravitational forces of visible stars, then an invisible object must be affecting it, and this invisible star may be a black hole.

    e. The study of gamma rays helps to locate supernovae, pulsars, neutron stars, and black holes.

13. Space-based astronomy can capture all the radiations while ground-based radiations can only capture radio, visible, or some infrared radiations.

14. The attempts at locating observatories in space are

- Hubble telescope launched in 1990 is used to study visible light.
- Gamma Ray Observatory launched in 1991 will study gamma radiation.
- Advanced X-ray Astrophysics Facility and Space Infrared Facility will be launched in the future.
- Cosmic Background Explorer launched in 1992 studies cosmic radiation which reveals how the universe was formed.
- The International Ultraviolet Explorer was launched in 1987.

15. *Voyager 1 and 2* launched in 1977 have sent

- pictures of Jupiter, Saturn, Uranus, and Neptune
- pictures of the magnetic fields around Uranus

16. a. A close-up view would greatly enhance knowledge of the universe.

    b. The time-factor of space travel is a disadvantage. According to the calculations in Activity 1 it would take a space probe 15.9 years just to reach the outer limits of the solar system.

Section 1: Activity 3

1. a. They appear to bend into semi-circular waves.

   b. This property of waves is called diffraction.

   c. The size of the slit affects the diffraction (i.e., the smaller the slit, the greater the diffraction).

   d. The wavelength (λ) of the waves also affects diffraction (i.e., the larger the wavelength, the greater the diffraction).

   e. i. $v = f\lambda$

      ii. $f = \dfrac{1}{T}$

      iii. No, these all appear to remain the same.

   f. No, particles do not appear to diffract.

   g. All waves diffract while particles do not.

2. The resulting amplitude will be $2.00 \text{ cm} + 1.00 \text{ cm} = 3.00 \text{ cm}$.

3. a. The resulting amplitude will be $2.00 \text{ cm} + (-1.00 \text{ cm}) = 1.00 \text{ cm}$.

   b. No, particles cannot produce nodes and antinodes.

c. Only waves can interfere; particles cannot.

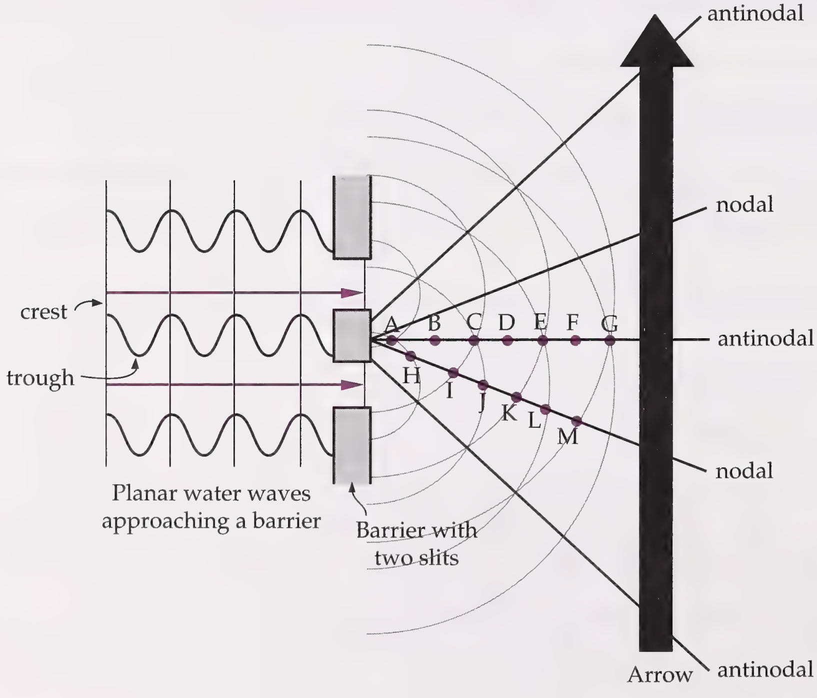
4. a.

Point	What type of waves are superimposing at each point?	What type of interference is occurring at each point?	What is the name of the resulting wave at each point?
A	2 crests	constructive	antinode
B	2 troughs	constructive	antinode
C	2 crests	constructive	antinode
D	2 troughs	constructive	antinode
H	1 crest, 1 trough	destructive	node
I	1 crest, 1 trough	destructive	node
J	1 crest, 1 trough	destructive	node
K	1 crest, 1 trough	destructive	node

b. It could be called an antinodal line.

c. It could be called a nodal line.

d.



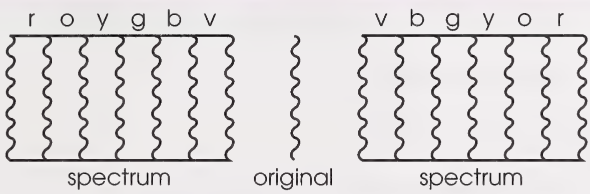
e. You would first experience an antinodal line (larger crests and troughs), then a nodal line (no wave), then an antinodal line, and so on.

f. It is caused by diffraction and interference of waves.

g. No, particles do not appear to produce this pattern.

h. Waves diffract and interfere, particles cannot.

The following chart gives answers for questions 5, 7, 8, and 9.

Light Source	Sketch of the observed pattern	Distance from centre bright line to centre of 1st bright image line x (cm)
White Light		
Light with Red Filter		42 cm
Light with Blue Filter		24 cm

6. This is called a spectrum of white light caused by diffraction and interference of light.

10. Yes, light diffracts and interferes.

11. This proves that light is a wave.

12. It shows that white light is composed of all visible colours of the electromagnetic spectrum.

13. Red diffracts the most.

14. Different colours have different wavelengths.

15. Red would seem to have the largest wavelength since it diffracted the most.

Section 1: Activity 4

1. a. The colour bands observed in the bright-line emission spectrum are in the same position as the dark bands in the dark-line absorption spectrum.

   b. Because the two spectra correspond, the gas must be the same in both.

2. a. Hydrogen and sodium gas are in the sample.

   b. The star has the elements hydrogen and sodium present.

3. You would observe a continuous colour spectrum as well as a dark-line absorption spectrum.

4. The sun will emit a full spectrum because it is a dense hot, glowing gas of many elements.

5. The atmosphere has only a few cool gaseous elements surrounding it. This is why you see the dark-line absorption spectrum rather than the bright-line spectrum produced by a glowing gas.

6. The atmosphere surrounding the sun is called a corona.

7. Yes, the spectrum is missing two dominant yellow lines.

8. This suggests there is cool sodium gas surrounding the sun.

9. The electron absorbs energy.

10. It absorbs this energy from the energy supplied to the atom by white light.

11. You will observe an absorption spectrum.

12. The electron will be in an excited state.

13. It will emit energy.

14. An emission spectrum will be observed.

15. Both spectra involve the same electron either jumping up or returning to the same two energy levels for a particular line.

Section 1: Follow-up Activities

Extra Help

1. a. All electromagnetic radiation travels at 3.00×10^{8} m/s.

   b. Propagation of light can reveal the distance to stellar objects.

   c. A light-year is a measure of distance.

   d. A light-year is the distance light can travel in 1 a (i.e., 9.46×10^{15} m).

2. a. The technology that gathers information using reflecting and refracting of light is telescopes.

   b. The first refracting telescope was developed by Galileo.

   c. The first reflecting telescope was developed by Newton.

   d. Three types of reflecting telescopes are Newtonian, Cassegrain, and Coudé.

   e. Two electromagnetic radiations that reach Earth's surface are radio waves and visible light.

   f. Telescopes that use reflection or refraction of light can reveal position, brightness, and topography of stellar objects.

3. a. Diffraction and interference of light shows that light and all electromagnetic radiation travel as waves.

   b. Three types of spectra observed by diffraction and interference of light are continuous spectra, bright-line emission spectra, and dark-line absorption spectra.

   c. The different spectra can reveal the chemical composition of a star and its atmosphere.

Enrichment

1. **Textbook question 1:** Answers may vary. EMR which can be used are radio, infrared, visible, UV, x-ray, or gamma radiations. The particular information of each can be found on pages 334–339 of your text. You may feel that all are equally important since each type of radiation contributes its own information about the universe.

   Textbook question 2: This question involves research into the different probes and could include Voyager 1 and 2, Mariner 1 and 2, the Venus Probes, the Mercury Probes, the Lunar Landings, and so on.

2. **Textbook question 2:** Both *The Edmonton Journal* and *The Calgary Herald* have a science section in every Sunday paper. If you follow this section over a period of several months you will find appropriate articles. In addition, other newspaper sections and magazines may carry appropriate articles from time to time.

Section 2: Activity 1

1. Increasing the amount of air increases combustion of the gas.

2. The temperature of the flame will be higher.

3. The energy in the flame will also increase.

4. Red will be the lowest temperature.

5. Blue will be the highest temperature.

6. As frequency of light increases, the amount of energy will also increase.

7. a. The surface temperature range of a typical red star is 1900 K to 3500 K.

b. A red star is a class N star.

c. R Lep is an example of a class N star.

8. a. The surface temperature range of a typical blue star is 28 000 K to 50 000 K.

b. A blue star belongs to the class O.

c. <chi> Per, Alnilan, and <epsilon> Orion are examples of class O stars.

9. The sun is a class G star.

10. Helium becomes the most dominant element as stars get hotter.

Section 2: Activity 2

1. The two bulbs would appear to have the same brightness.
2. Bulb 2 would be brighter.
3. The distance to an object determines brightness.
4. The two bulbs would appear to have the same brightness.
5. Bulb 2 (the 200 W bulb) would be brighter.
6. The power rating determines brightness.
7. A 200 W bulb has a greater luminosity.
8. Rigel has 40 000 times more luminosity than the sun.
9. The luminosity is compared to the sun which has been given a luminosity of one.
10. Sirius A is the brightest.

11. a.

Factor	Explanation
• Temperature of the stars	• The temperature will decrease as you move from left to right.
• Dominant spectrum colour of the stars	• The colour changes from blue to red as you move from left to right.

b.

Factor	Explanation
• Brightness or visual magnitude of stars	• The brightness increases.
• Size of stars	• The size increases.

12. a. 1 AU = 1 radius of Earth's orbit
2 AU = 1 diameter of Earth's orbit
7 AU = 3.5 diameters of Earth's orbit

Thus, Betelgeuse is as large as 3.5 diameters of Earth's orbit.

b. $$\frac{1 \text{ AU}}{1.50\times10^{11}\text{ m}} = \frac{7 \text{ AU}}{d}$$

$$d = 1.05\times10^{12}\text{ m}$$

$\therefore$ Betelgeuse is 1.05×10^{12} m in diameter.

13.

• Main Sequence Stars	• a pattern of stars along a line near the top of the diagram
• Giant Stars	• a pattern of stars along a line near the bottom of the diagram
• Dwarf Stars	• a pattern of stars along a diagonal line near the middle of the diagram

14. a. The hottest and brightest stars along the main sequence line would be near the top on the left.

b. The coolest and dimmest stars along the main sequence line would be near the bottom on the right.

c. Blue stars would be in the upper left of the diagram.

d. Red stars would be in the lower right of the diagram.

e. The sun would be in the middle of the main sequence line.

Section 2: Activity 3

1.

Fundamental Particle	Symbol	Charge (C)	Mass (kg)
Electron	e^- or $^{0}_{-1}e$	-1.60×10^{-19} C	9.11×10^{-31} kg
Proton	p^+	$+1.60\times10^{-19}$ C	1.67×10^{-27} kg
Neutron	n^o	0	1.67×10^{-27} kg
Deuteron	$^{2}_{1}H$	1.60×10^{-19} C	3.34×10^{-27} kg
Neutrino	v	0	0
Positron	e^+ or $^{0}_{+1}e$	$+1.60\times10^{-19}$ C	9.11×10^{-31} kg

2. The two processes that result in gamma radiation are the combining of a positron $\left(e^+\right)$ and an electron $\left(e^-\right)$ and the fusion of hydrogen $\left(^{1}_{1}H\right)$ and deuteron $\left(^{2}_{1}H\right)$.

3. Since two light helium nuclei are required for Step 3, then Step 2 must occur twice before Step 3 can occur.

4. $\Delta E = \Delta mc^2$

$$= \left(4.68 \times 10^{-28}\ \text{kg}\right)\left(3.00 \times 10^{8}\ \tfrac{\text{m}}{\text{s}}\right)^2$$

$$= 4.21 \times 10^{-11}\ \text{J}$$

5. Since the mass of the sun $= 1.989 \times 10^{30}$ kg, then

$$\frac{6.0 \times 10^{11}\ \text{kg}}{3.17 \times 10^{-8}\ \text{a}} = \frac{1.989 \times 10^{30}\ \text{kg}}{n}$$

$$n = 1.1 \times 10^{11}\ \text{a}$$

This process could last for 110 000 000 000 a at this rate of conversion of hydrogen!

6.

Source of energy	Temperature at which each source of energy can occur
• gravitational forces	• below 1 000 000 K
• nuclear fusion in a proton-proton chain (H fuses to form He)	• between 6 000 000 K and 16 000 000 K
• carbon atoms fuse to form nitrogen (carbon cycle)	• above 15 000 000 K

7. a. The sun is about 5 billion years old.

   b. It will remain as it is today for about another 5 billion years.

8. The sun will become a dwarf in about 25 billion years.

9. Interstellar dust, present sun, red giant, sub-giant, variable star, dwarf

10. The sun will be able to sustain life on Earth only during Stage I.

11. No, only stars starting with a larger mass than the sun can become supergiants.

12. No, the life cycle depends on a star's beginning mass.

13. As the mass of a star increases, its life span decreases.

14. The relationship between mass and life span is such because stars with a large initial mass start the main sequence with a much higher temperature. This higher temperature consumes fuel at a much faster rate—far faster than what their larger initial mass will allow.

15. a. It depends on the initial mass. The star will follow path 1 if the mass is less than $M_\odot$, path 2 if the mass is around 5 times $M_\odot$, and path 3 if the mass is around 10 times $M_\odot$.

   b. If the remaining mass of the star after all fusion stops is more than 1.4 times $M_\odot$, then it becomes a neutron star. If the remaining mass is more than three times $M_\odot$, then it becomes a black hole.

Section 2: Follow-up Activities

Extra Help

1. a. The sun is yellow.

   b. The colour indicates the surface temperature of the sun and its position along the main sequence branch line for stars on the H–R diagram.

   c. The sun's temperature is around 4900–6000 K.

2. The brightness of a star depends on its luminosity and its distance from Earth.

3. a. The unit for distance to a star is a light-year which is equivalent to 9.46×10^{15} m.

   b. The unit for star size is AU or astronomical units. ($1\,\text{AU} = 1.50 \times 10^{11}$ m which is the radius of the orbit of Earth around the sun.)

   c. The unit for star mass is $M_\odot$, where $1\ M_\odot = 1.99 \times 10^{30}$ kg or the mass of the sun.

4. a. hydrogen atom: ${}^{1}_{1}\text{H}$
   deuterium atom: ${}^{2}_{1}\text{H}$
   light helium atom: ${}^{3}_{2}\text{He}$
   helium atom: ${}^{4}_{2}\text{He}$
   neutrino: v
   gamma radiation: γ
   positron: ${}^{0}_{+1}\text{e}$
   electron: ${}^{0}_{-1}\text{e}$

   b. ${}^{2}_{1}\text{H}$ is a heavier hydrogen nucleus called deuterium. It has a neutron in the nucleus.

   c. ${}^{3}_{2}\text{He}$ is a lighter helium isotope. It has one less neutron in the nucleus than a regular helium atom.

   d. Other particles studied are neutrinos, positrons, and gamma radiation.

Enrichment

1. Answers will vary but your report should include how the neutrino was first detected and by whom.
2. Student responses may vary but should answer the questions posed.

Section 3: Activity 1

1. This light might reveal how the universe began.

2. a. The dough represents all space of the universe.

   b. The raisins represent galaxies in the universe.

c. All other galaxies are moving away from us.

d. No, the farther away a galaxy is the faster it is moving away from us.

e. Distance from us is the factor that determines the speed of galaxies relative to us.

3. This is called an expanding universe.

4. a. Yes, the waves would appear to hit you at a faster rate.

   b. The frequency or the number of waves per second appears to increase.

   c. No, the frequency from the source is the same.

   d. As a receiver moves towards a source, frequency appears to increase.

5. a. Yes, the waves would hit you at a slower rate or fewer waves per second.

   b. The frequency of the waves appears to have decreased.

   c. As a source moves away from a receiver, the frequency appears to decrease.

6. a. The frequency would appear to decrease.

   b. The wavelength of the light would appear to increase because there is the following relationship between frequency and wavelength:

$$\text{wavelength} \propto \frac{1}{\text{frequency}}$$

   c. This change is called a redshift because there is always a shift toward the red end of the spectrum.

   d. The faster a receding star, the greater the shift of colour in its spectrum towards the red end.

   e. The faster its speed, the farther away it is in the galaxy.

7. a. The frequency of the light would appear to increase.

   b. The wavelength of the light would appear to decrease.

   c. This would be called a blueshift.

8. a. The cluster galaxy in the constellation Hydra has the greatest redshift.

   b. It is moving the fastest away from us, thus it has the lowest apparent frequency and the greatest shift towards a red wavelength.

   c. The largest cluster galaxy appears to be the Virgo cluster in the constellation Virgo.

   d. It appears the largest because it is the closest.

9. a. $v = 70\frac{\text{km}}{\text{s}} = 7.0\times10^{4}\ \frac{\text{m}}{\text{s}}$

$\Delta d = 3.262\times10^{6}$ light years $= 3.09\times10^{22}$ m

$$\begin{aligned}\therefore \Delta t &= \frac{\Delta d}{v}\\ &= \frac{3.09\times10^{22}\ \text{m}}{7.0\times10^{4}\ \frac{\text{m}}{\text{s}}}\\ &= 4.41\times10^{17}\ \text{s}\end{aligned}$$

b. $4.41\times10^{17}\ \text{s}\times\frac{1\ \text{min}}{60\ \text{s}}\times\frac{1\ \text{h}}{60\ \text{min}}\times\frac{1\ \text{day}}{24\ \text{hr}}\times\frac{1\ \text{yr}}{365\ \text{days}} = 1.4\times10^{10}\ \text{a}$

Section 3: Activity 2

1. This theory is called the steady-state theory.
2. According to the steady-state theory the universe has always existed and has always been expanding.
3. This theory proposes that the universe is expanding at a constant rate.
4. Matter is always being created to fill this void or empty space.
5. Radio waves showed that there were more weak radio waves farther away than strong radio waves close to us; this proves that the structure of the universe is not constant and therefore refutes the steady-state theory.
6. According to the big-bang theory the universe began with a gigantic explosion that sent matter and radiation in all directions.
7. The big-bang theory proposes that initially radiation was converted to matter which then formed the stars and galaxies.
8. According to the theory the universe's eternal supply of matter was created about one minute after the big-bang.
9. The galaxies were formed from this matter millions of years later.
10. The universe is expanding at greater and greater speeds in all directions.
11. Evidence of weak radio waves emanating from all directions in the universe is the most significant support for this theory.
12.

THREE POSSIBILITIES FOR THE FUTURE OF THE UNIVERSE		
Possibility	**Factor that Affects This Possibility**	**Eventual Fate of the Universe**
If the universe is **open**	Matter in the universe is not dense enough for gravitational forces to affect it and have the universe start contracting.	The universe will continue to expand at a rate that is almost constant, becoming less and less dense.

If the universe is **closed**	Matter in the universe is dense enough for gravitational forces to prevent further expansion and eventually start a contraction.	The universe might then contract causing galaxies to come together and start another big-bang in about 50 billion years. This would start the process again.
If the universe is neither **open** nor **closed**	Mattter in the universe is not a factor for this possibility.	The universe will then expand forever, but at a decreasing rate.

Note: The *Visions 3* textbook suggests that in the open universe the rate of expansion is increasing. Other sources suggest that the rate of expansion in an open universe is slowing down slightly and will eventually become fairly constant but definitely not increasing. In other words the size of the universe is increasing, but the rate at which the size is increasing is slowing down.

13. **Textbook question 6:** A defence for the statement is: All galaxies appear to be receding from us; therefore, we must be the centre of the universe. An argument against the statement is: If space is expanding everywhere, then every point would appear to be the centre of the universe. It is highly unlikely that we are actually the exact centre of the universe.

Section 3: Follow-up Activities

Extra Help

1. a. Our galaxy is called the Milky Way Galaxy.

   b. All galaxies are moving away from the Milky Way at increasing rates.

   c. It is thought that the universe is about 14 billion years old.

2. a. The Doppler effect proves all galaxies are receding.

   b. The wavelength appears to increase; therefore, you have a shift towards red, which is a larger wavelength.

3. a. Two opposing theories of creation of the universe are the steady-state theory and the big-bang theories.

   b. The big-bang theory is accepted at the present time. The steady-state was discredited through radio wave studies which showed that matter was not constant throughout space.

4. Three possible theories for the future of the universe are open, closed, or neither open nor closed.

Enrichment

1. **Textbook question 8:** The open universe is the favoured model. However, the possibility of dark matter is starting to change this. An argument for the closed universe is the increase in the calculated density of matter in the universe. Do additional library research on these two theories and the supporting evidence for each.

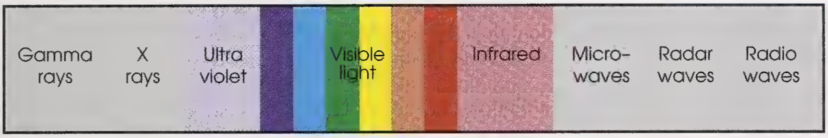
2. **Textbook question 1:** Your answers will vary but may include parts of steady-state theory, big-bang theory, or a theory of Genesis.

   Textbook question 2: Your responses may vary, but may include suggestions from Careers in Astronomy found on page 346 of the *Visions 3*.

Colour Diagrams and Photographs

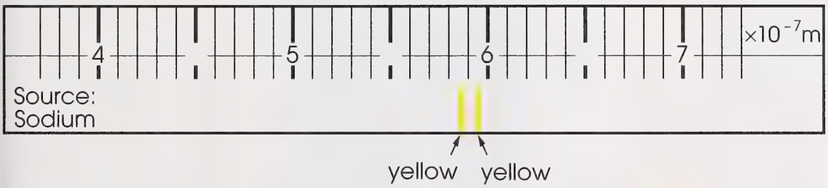
Electromagnetic Radiation Spectrum

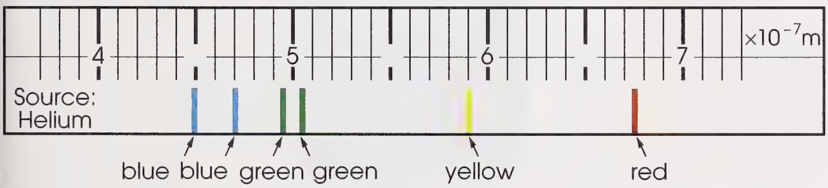
Section 1: Activity 2

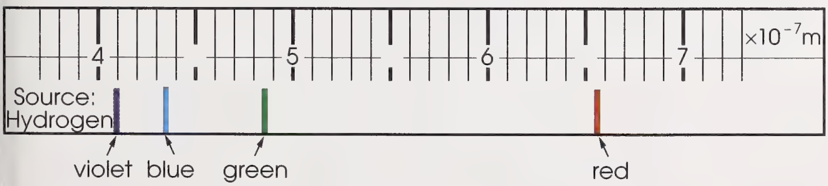


Samples of Spectra of Particular Elements

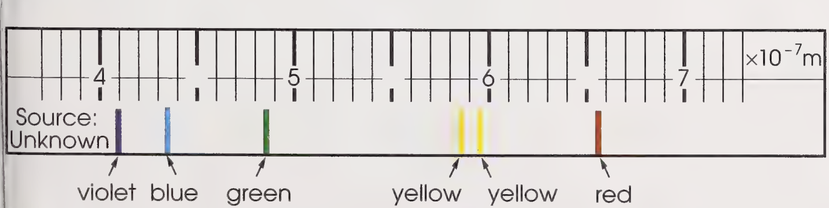
Section 1: Activity 4







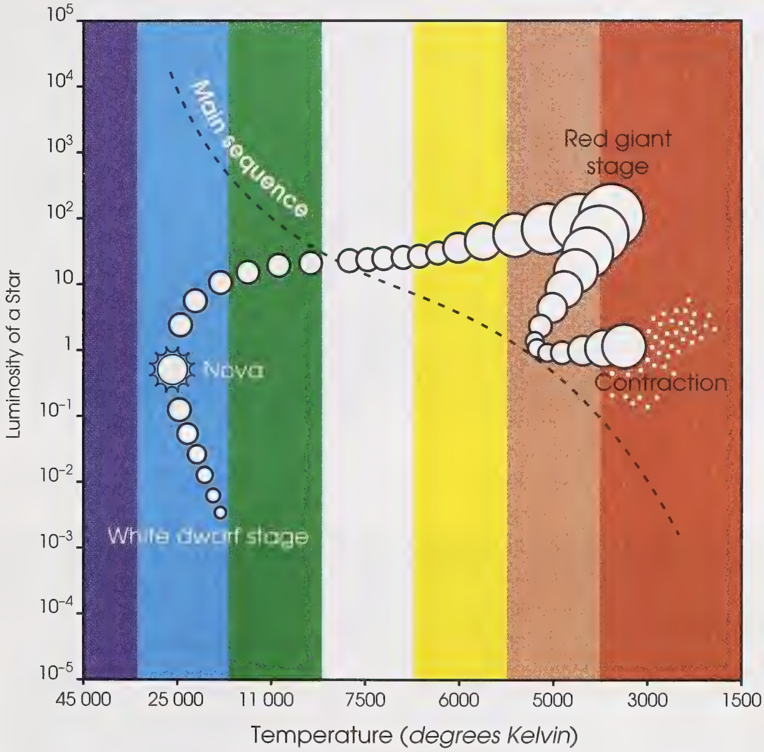
Spectra for question 2.a.



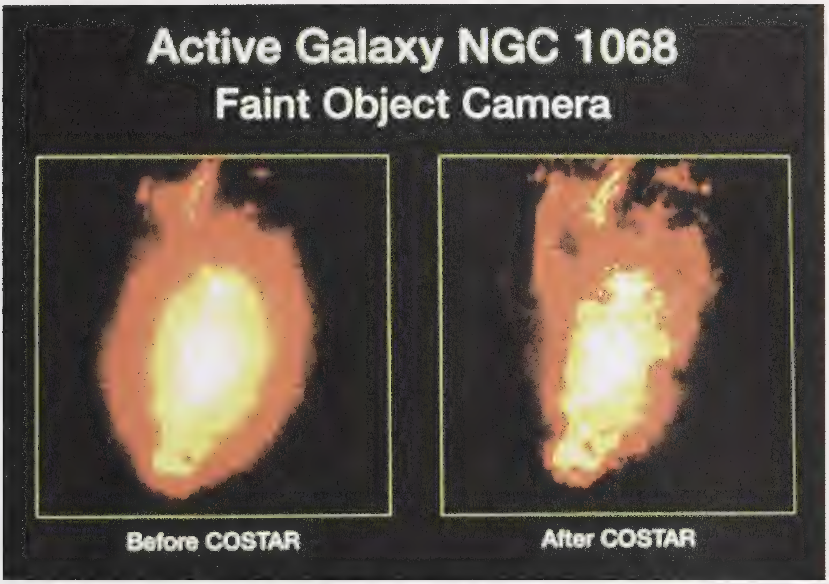
Section 2: Activity 2

H-R Diagram

Shows luminosity and temperature of a particular star (contraction, main sequence, red giant, white dwarf) as it moves its way through the respective stages.

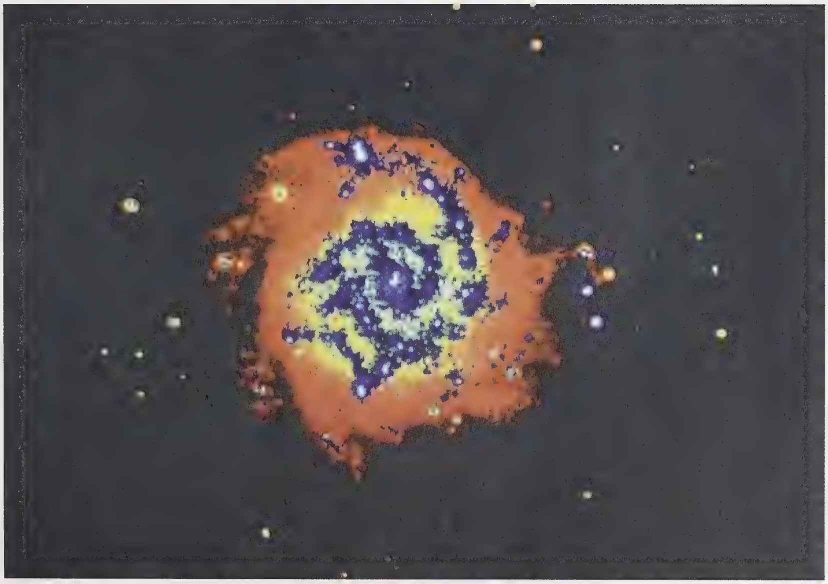


Before and After Images from the Hubble Space Telescope



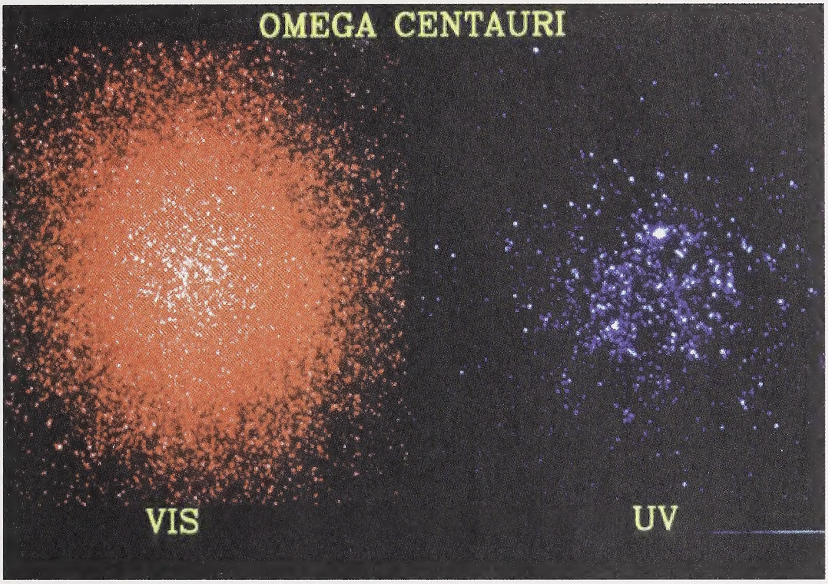
NASA

M74 Spiral Galaxy in UV Light



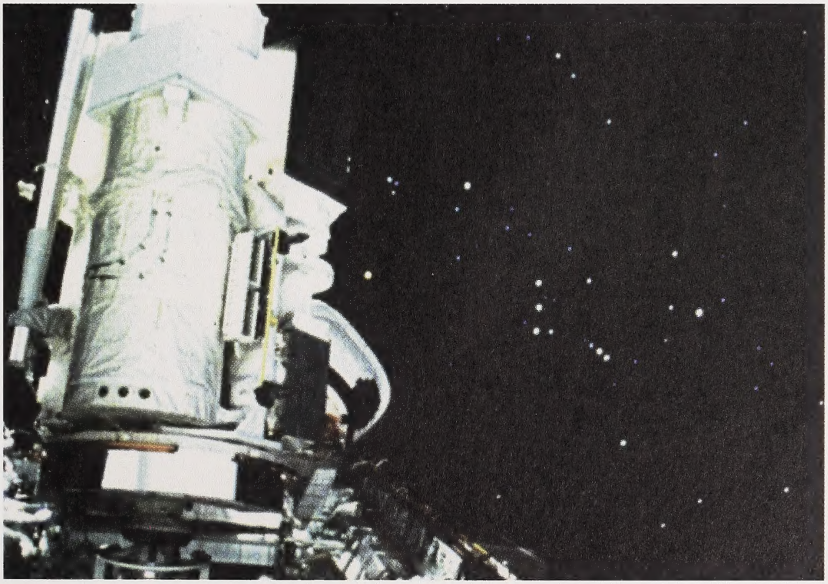
NASA

Omega Centauri in Visible Light and UV Light



NASA

Astro-1 Space Telescope and Orion Constellation in the Background



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